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SIZE OF SEED IN RELATION TO SIZE AND SHAPE OF ROOT IN SWEDE TURNIPS

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INTRODUCTION

Among the factors of quality in the regulations under the Seeds Act it is stated that seeds,within reasonable limits, shall be uniform. Uniformity in size, while it is taken into consideration in applying the regulations, is not precisely defined. The seeds of turnips may vary quite markedly in size but there is little information on the relationship between size of seed in this crop and yield. In February, 1946, this question was brought to the attention of the Division of Plant Products by a prominent grower of swede turnips. He contended that the smaller seeds were slower to germinate and consequently produced smaller roots than the larger seed and also that there was a greater variation in type of roots, when the seed used varied in size. Uniformity in type and size of root are important factors in marketing the crop.

At the same time this grower provided a sample of registered seed of one of the most widely grown varieties, Laurentian, to illustrate his contention. It was decided to conduct some trials on the plots of the Plant Products Division at Sackville, N.B., using this material and this was done during the summer of 1946. At the same time, tests of germination speed and germination capacity were carried out in Seed Research Laboratory, Ottawa. These are discussed in Part I of this paper. Since the findings of these trials seemed to run counter to such as had been noted in the literature, it was felt that a repetition of the work on a more extended scale should be undertaken. This was planned for the growing season of 1947 but could be carried out only in part owing to the destruction of some of the plots. This work is considered in Part II.

Part III deals with size of seed in relation to shape of root.

REVIEW OF LITERATURE

While a considerable amount of work has been done on size of seed in relation to plant development, root crops do not appear to have received as much attention as other types of crop. Findlay (4) in 1919, using various crop seeds, including turnip, studied the problem from two points of view, namely (*a*) different sized seeds in the same sample and (*b*) different sized seeds in different samples of the same kind of seed. The results with turnips showed slight, but consistent, increases in yield with the larger seeds of a given sample but small seeds of a good strain proved superior to

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large seeds of a poor strain. Results very similar to these have been obtained at the Ontario Agricultural College, according to a communication from G. P. McRostie. Other workers have investigated the effect of size of seed on yield and growth using a variety of crop plants other than roots (except beets, in which "seed", however, connotes the beet-ball and which therefore need not be considered here). Brenchley (2) concluded that with short-lived species there was an advantage in using heavier seeds but that the advantage became less marked, though still in evidence, with longer-lived species. A somewhat similar conclusion was drawn by Oexemann (7) who found that the importance of the seed weight factor was greatest in the early stages of development but the advantage became less as the plant matured and was lost at maturity. The mortality rate, however, was higher among seedlings from small seeds. His conclusion is similar to that of Kotowski (5) who found that size of seed influences the size of plant during the first 60 days but that the effect disappears after that time. Various Russian workers have studied the problem in grains (3, 9 and 10) and in cucurbits (6) and have concluded that the larger seeds give a greater yield.

As to speed of germination, Alessandretti (1) found a pronounced difference in favour of the smaller seeds although there was no difference between large and small seeds in germination capacity. He concluded that the only advantage of large seeds lay in their more voluminous food reserves from which deeply covered seeds might benefit.

Part I. 1946 Growing Season

MATERIALS

The sample as received consisted of a number of sub-samples of a lot of Registered Laurentian Swede as follows:

Lab. No.	Fraction
RL 140	Representing the bulk sample
A	Seed retained by a 1/14 screen
B	Seed retained by a 1/15 screen
C	Seed retained by a 1/16 screen
D	Seed retained by a 1/18 screen
E	Seed retained by a 1/22 screen

These screen sizes were represented in the bulk sample in the following proportions:

Screen size	Per cent of bulk sample
1/14	29.5
1/15	30.2
1/16	31.3
1/18	7.5
1/22	1.5
	100.0

In addition another sample of Laurentian Swede was grown in the plots at Sackville to serve as a check.

Speed of germination and growth

METHODS

Studies of speed of germination were made by a method developed in the Seed Research Laboratory which has proved very sensitive for several kinds of seed. As it has not previously been described, it is given here in some detail. It actually measures speed of germination and initial growth.

Each seed is germinated in a shell vial. For small seed such as the present, vials approximately 67 mm. × 17 mm. are used. The vials are, however, carefully calibrated and selected as to diameter size so that the diameters in an entire series are as equal and uniform as possible (± .01″).

A measured volume of dry sand of rather uniform grain size (the exact size is not important within a range of about 0.5 mm. to 1.5 mm.) is placed in each vial and sufficient water added so that when shaken and tapped the sand is all wetted and has a thin film of water over the surface. Care must be taken that the surface is level. One seed is then planted as exactly as possible in the centre and a measured volume of dry sand poured on top, the surface being levelled by gentle shaking. The prepared vials are placed in a box containing dividing strips (similar to those in an egg-crate) and the whole placed in a controlled temperature cabinet. It is advisable to run a whole series in one cabinet because slight differences of temperature between two cabinets will materially affect the results.

In the present series the shell vials were 0.58″ in diameter (internal), 5.3 cc. of sand were placed in each and 2 cc. of water added. The seed was covered with 2.6 cc. of dry sand. The tests were placed in a germinator at 20° C.

The germinating seedling almost invariably grows straight up the centre of the column of dry sand above it and it can easily be detected the moment it breaks surface. Readings are made as often as necessary during the period when surface penetration is occurring.

RESULTS

Sample E was not used in these tests since there would not then have been sufficient seed of this size for the field trials.

Twenty-five seeds each of samples A, B, C and D were planted as described, between 2.30 p.m. and 3.05 p.m., March 12, 1946. First penetration occurred at about 4.50 p.m., March 15. Table 1 gives the results.

Table 1.—Speed of germination—vial tests

Date	Time	Seedlings penetrated			
		A	B	C	D
March 15	4.50 p.m.	1	1	0	4
March 16	9.15 a.m.	14	17	14	10
March 16	11.35 a.m.	18	19	17	17
March 18	9.15 a.m.	25	25	23	23

Two seeds of each of C and D failed to germinate. Bearing this in mind there is little, if any, tendency on the part of the smaller seeds to lag in germination speed in relation to the larger.

The seedlings were carefully removed, washed and measured with the results given in Table 2.

TABLE 2.—AVERAGE LENGTHS OF SEEDLINGS—VIAL TESTS

Sample	No. seedlings	Mean length, cm.	S. D	S. D.$_{(mean)}$
A	25	2.88	0.625	0.125
B	25	2.79	0.604	0.121
C	23	3.06	0.548	0.114
D	23	3.10	0.704	0.147

The greatest difference occurred between D and B, a difference of 0.31 cm. This gives t 1.63. Since this is the greatest difference among six possible comparisons, t = 2.8 at the 5 per cent point. Thus the difference is not significant.

In a second series of tests, 50 seeds of each of samples A, B, C and D were planted between blotters and placed in a germinator at 20° C. These blotters were examined three times a day and the initiation of germination of each seed recorded.

The tests were planted at 3.30 p.m., March 18, 1946. Germination was completed by March 22 and at 2.35 p.m. of that date, hypocotyls of all seedlings were measured. Tables 3 and 4 give the results.

TABLE 3.—SPEED OF GERMINATION—BLOTTER TESTS

Date	Time	Seeds germinated			
		A	B	C	D
March 19	11.00 a.m.	1	5	2	2
March 19	3.00 p.m.	13	12	14	12
March 20	9.45 a.m.	47	50	47	43
March 20	4.30 p.m.	—	—	50	45
March 22	*	3	—	—	5

* Dead seeds or abnormal sprouts.

Table 3 agrees in general with Table 1. The 3 and 2 seeds which germinated in samples C and D, respectively during the day of March 20 are too few and the delay in germination too brief to be of significance in relation to the present problem.

In comparing Tables 1 and 3 it should be borne in mind that in Table 1 it is penetration of seedlings that was recorded; in Table 3 it is the first evidence of emergence of the radicle from the seed coat that was recorded.

TABLE 4.—LENGTHS OF HYPOCOTYLS—BLOTTER TESTS

Sample	No. of seedlings	Mean length, cm.	S. D.	S. D.$_{(mean)}$
A	47	1.30	0.247	0.036
B	50	1.27	0.285	0.040
C	50	1.38	0.235	0.033
D	45	1.23	0.337	0.050

This accounts for the differences in elapsed time before the first records in the two tables.

The greatest difference in length of hypocotyl occurred between C and D, giving a t-value of 2.4. Since this is the greatest difference among six possible comparisons, the 5 per cent point for the value of t is about 2.7. Thus the difference is not significant and the blotter tests confirm the conclusion of the vial tests.

These tests show that the germination capacity was about 96 per cent.

SIZE OF ROOTS PRODUCED BY SEEDS OF DIFFERENT SIZES

METHODS

Each size of seed was planted in duplicate rows in two blocks on a level and uniform part of the experimental field at Sackville. The total weight of roots in each row was determined and each root was measured by means of a tree caliper graduated in tenths of an inch, the polar and equatorial diameters being recorded. Where the roots were not typically globe-shaped, which occurred in a few cases, two equatorial measurements were taken and these were averaged in the calculation of the approximate volumes as described below.

On an adjacent plot another lot of Laurentian swede was grown from which 300 roots were harvested and measured, for purposes of comparison.

A preliminary investigation of the raw data showed that it would be necessary to study the volumes if definite conclusions were to be drawn.

As an approximation to the volume of individual roots, the formula for the volume of an ellipsoid was used

$$V = \frac{4}{3} a\ b\ c$$

where *a*, *b* and *c* are the three semi-axes of the object. It was assumed that the roots were reasonably circular in cross-section so that half the figure for width would represent each of two of the semi-axes and half the figure for depth would represent the third. The data for each root were converted into volume and the resulting figures used in the analysis which follows.

The ratio: Mean weight/mean volume was calculated from the weights and volumes of the roots produced by each size of seed and these ratios are given in Table 5.

TABLE 5.—WEIGHT/VOLUME RATIOS

Sample	Ratio	Sample	Ratio
Bulk	0.0402	C	0.0394
A	0.0395	D	0.0376
B	0.0386	E	0.0375

These ratios are fairly constant, which suggests that the method of computing volumes should be satisfactory.

RESULTS

In Table 6 are presented the average weights and volumes together with the numbers of roots harvested.

TABLE 6.—MEAN WEIGHTS IN POUNDS AND VOLUMES IN CUBIC INCHES OF ROOTS—1946

Sample	Block 1			Block 2			Volumes, average of blocks
	No.	Means		No.	Means		
		Weight	Volume		Weight	Volume	
Bulk	81	2.48	60.9	44	4.41	111.1	—
A	86	2.84	74.0	61	3.95	96.9	83.5
B	79	2.87	77.1	93	2.61	65.2	70.7
C	66	3.12	83.4	51	3.35	79.6	81.7
D	64	3.31	92.8	42	4.69	117.5	102.6
E	60	3.65	93.2	58	2.90	81.4	87.4
Check	300	—	98.8	—	—	—	—
Significant difference between any pair at 5 per cent level							6.03

Examination of this table reveals a very marked negative relationship between the number of roots harvested and the mean weights or volumes such that it is evident that root competition is an important factor in bringing about variations in yield.

TABLE 7.—ANALYSIS OF VARIANCE OF VOLUMES OF SWEDES PRODUCED BY SEEDS OF DIFFERENT SIZES, 1946

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between means of ten plots	9	1931.58	—
Between means of blocks	1	40.49	40.49
Between means of seed sizes	4	1218.01	304.50
Interplot error	4	673.08	168.27
Intraplot error	650	—	29.43

The interplot mean square is large compared to intraplot error; using the interplot mean square for estimating significance therefore,

$$F = \frac{304.50}{168.27} = 1.81$$

The 5 per cent point is 5.69, so that the effect of seed size is not significant. Such correlation as exists between seed size and root size is negative (−0.49) and not significant.

The check sample with 300 roots and mean volume of 98.8 compared with the bulk, of 125 roots and mean volume 78.6, and with the average of fractions A to E with a mean volume of 80.6, illustrates the variation in root size of seeds of the same variety of different origin.

Part II. 1947 Growing Season

MATERIALS

Two samples (Nos. 72 and 73) of Registered Laurentian Swede grown in the Maritimes were obtained for this study. They were separated into the same series of fractions as was the 1946 material, using a zinc screen with round holes, and each fraction was tested for germination in the Seed Research Laboratory. The following tabulation shows these particulars for the two samples used:

Lot	Size of screen retaining	Per cent by weight		Germination	
		Sample 72	Sample 73	Sample 72	Sample 73
A	1/14	26.5	31.2	92.5	96.0
B	1/15	34.9	37.7	91.0	96.5
C	1/16	20.5	17.6	90.5	97.0
D	1/18	17.1	12.5	88.5	96.5
E	1/22	1.0	1.0	90.0	91.0

There were no significant differences in the germination capacity except for Lot E of sample 73 which was just significantly lower than the other four lots of that sample. Sample 73, however, has a significantly higher germination than Sample 72.

METHODS

Detailed speed of germination trials were not made on these lots but a figure was obtained, indicative of germination speed, by the use of the formula

$$\frac{\text{Average germination at 4 and 7 days}}{\text{Final germination}} \times 100$$

Volumes were investigated in the same way as in the 1946 trials.

Field trials were conducted at Sackville, Macdonald College and Ontario Agricultural College. Unfortunately, at the two latter places, root maggot and weather, respectively, spoiled the plots. Some observations were possible at Macdonald College and these are referred to later.

At Sackville, plots for each sample were arranged in a Latin square, consisting of five sub-plots for each of the five seed sizes. Each sub-plot was 5 ft. × 10 ft. and consisted of three rows. From the centre of each plot, 25 roots were harvested. Seeds were sown more thickly than needed and the seedlings thinned for spacing only, without regard to vigour, to 15 plants per row. If a plant died, another was transplanted to replace it in order to protect those on either side but this plant was not used when taking records; instead, an extra plant from the row was used. Appropriate guard rows were provided.

In spite of these precautions, three plots had so few roots that they were not acceptable for the analysis of the results. All three were from the smallest size fraction, E; one was in sample 72 and two in sample 73. Estimates of the yields of the missing plots were made according to the method outlined by Snedecor (8). Analysis of variance was carried out on the corrected data. Where an occasional root was missing at harvest time, the roots on either side of the space were not taken.

The plots were seeded on June 13 and harvested on October 17; the total weight of roots was recorded for each seed size, as were the polar and equatorial diameters of each root. Unfortunately, no records were taken of the distance of the plane of greatest width from the top or of other root characteristics such as pronginess, etc.

The weight-volume ratios were as follows:

Seed lot	Weight/volume ratios	
	Sample 72	Sample 73
A	0.0362	0.0369
B	0.0375	0.0369
C	0.0369	0.0370
D	0.0372	0.0378
E	0.0366	0.0350

These ratios are reasonably constant and do not differ much from those of the 1946 trials.

RESULTS

Speed of Germination

Table 8 gives the germination speed based on the laboratory germination tests.

TABLE 8.—GERMINATION SPEED—BLOTTER TESTS

Lot	Germination speed per cent	
	In sample	
	72	73
A	91.6	95.1
B	92.0	96.1
C	94.8	95.6
D	93.2	97.2
E	89.2	94.0

No differences in speed of germination which would be of significance in the present problem are evident although it is to be noted that sample 73, which showed somewhat greater germination capacity also shows the greater germination speed.

Volumes

The mean volumes for each seed size, after corrections for the missing plots are given in Table 9.

TABLE 9.—MEAN VOLUMES IN CUBIC INCH OF ROOTS OF LAURENTIAN SWEDES PRODUCED FROM SEEDS OF DIFFERENT SIZES

Lot	Sample 72	Sample 73
A	68.0	83.0
B	69.7	76.9
C	66.8	77.6
D	71.3	76.3
E	75.3	78.3
*	15.6	10.1

* Significant difference between any pair at 5 per cent level.

While there are rather few values for determining correlation between seed size and size of root, it is interesting to note that sample 72 gave a correlation of -0.875 and sample 73 one of $+0.47$, one negative and one positive. Neither correlation is significant, however.

Analysis of variance is shown in Table 10.

TABLE 10.—ANALYSIS OF VARIANCE OF VOLUMES OF SWEDES PRODUCED BY SEEDS OF DIFFERENT SIZES

Source of variation	Degrees of freedom	Sum of squares	Mean square
Sample 72			
Total	23	2872.54	—
Rows	4	1099.16	274.79
Columns	4	175.16	43.79
Seed sizes	4	218.22	54.56
Interplot error	11	1380.01	125.46
Intraplot error	574	—	19.636
Sample 73			
Total	22	1686.14	—
Rows	4	152.69	38.17
Columns	4	767.38	191.85
Seed sizes	4	248.30	62.08
Interplot error	10	517.77	51.78
Intraplot error	550	—	26.15

For both samples the intraplot error is significantly less than the interplot error. Using the latter, therefore, for testing significance, it is seen to be either greater than (72) or about the same magnitude as (73) the seed size mean square. It must be concluded, therefore, that seed size was not influential in determining root size.

Part III. Type Study and Uniformity in Size of Roots

RESULTS

Type

In order to investigate the relationship between size of seed and shape of the resulting root, an index of shape was calculated for each root. This index was the ratio:

$$\frac{\text{Difference between polar and equatorial diameters}}{\text{Average of polar and equatorial diameters}}$$

The index is positive for long roots, zero for "round" roots and negative for a flattened root.

Type, in the Laurentian variety of swede, varies considerably from year to year and appears to be profoundly affected by the combination of soil and weather conditions and a timing factor.* Accordingly, direct comparisons cannot be made between the 1946 and 1947 plantings. However, results in any one trial should be reasonably comparative. Table 11 presents the mean shape indices given by seeds of different mean sizes and Table 12, the analyses of variance of the data.

TABLE 11.—MEAN SHAPE INDICES GIVEN BY SEEDS OF DIFFERENT MEAN SIZES

Size of screen retaining	Lot	Sample		
		1946	1947	
			72	73
1/14	A	0.060	0.145	0.109
1/15	B	0.057	0.142	0.114
1/16	C	0.058	0.144	0.124
1/18	D	0.029	0.129	0.094
1/22	E	0.021	0.095	0.033
*		0.124	0.044	0.056

* Significant difference between any pair at 5 per cent level.

The bulk sample in the 1946 trials gave a mean index value of + 0.0978 and the "check" sample, of 300 roots, gave a mean index value − 0.0133, values which differ highly significantly. This illustrates the variability in this factor between different stocks of the same variety.

The analysis of variance of the 1946 results gives an interplot variance much greater than the intraplot error so that great heterogenity among the plots was evident. The interplot variance is, in fact, slightly greater than that ascribable to seed size.

In samples 72 and 73, soil heterogenity is also evident if in lesser degree. In sample 73 the inter- and intra-plot variances differ significantly, though not in sample 72. However, as the interplot error is the limiting factor in the precision of the experiments, it should preferably be used in testing significance. This gives $F = 3.37$ for sample 72, the 5 per cent and 1 per cent points being 3.36 and 5.67, respectively and $F = 4.60$ for

* Communication from L. C. Raymond, Professor of Agronomy, Macdonald College, Quebec.

TABLE 12.—ANALYSIS OF VARIANCE OF SHAPE INDICES OF SWEDES PRODUCED BY SEEDS OF DIFFERENT MEAN SIZES

Source of variation	Degrees of freedom	Sum of squares	Mean square
1946			
Between means of 10 plots	9	0.039121	—
Between means of blocks	1	0.003648	0.003648
Between means of seed sizes	4	0.015449	0.003862
Interplot error	4	0.020024	0.005006
Intraplot error	650	—	0.000336
1947—Sample 72			
Total	23	0.037819	—
Rows	4	0.009989	0.002497
Columns	4	0.003361	0.000840
Seed sizes	4	0.013467	0.003367
Interplot error	11	0.011002	0.001000
Intraplot error	574	—	0.000620
1947—Sample 73			
Total	22	0.050096	—
Rows	4	0.002097	0.000524
Columns	4	0.002498	0.000625
Seed sizes	4	0.029469	0.007367
Interplot error	10	0.016032	0.001603
Intraplot error	550	—	0.000678

sample 73, the 5 per cent and 1 per cent points being 3.48 and 5.99, respectively. Thus the effect of seed size on type of root produced may be considered significant.

The magnitude of these effects is illustrated in Table 11, which shows a definite tendency for the two smallest seed groups to produce flatter roots. In the 1946 results the design of the trial was such that the significance of this tendency could not be established. In sample 72 it will be noted that lot E differed significantly from lots A, B and C but not from lot D, whereas in sample 73, lot E differed significantly from all other lots.

Uniformity in Size

As a measure of uniformity in the sizes of roots produced by the different seed-size groups, the coefficients of variability have been calculated $\frac{\text{S. D.}}{\text{Mean}}$ and are given in Table 13.

TABLE 13.—COEFFICIENTS OF VARIABILITY OF ROOT SIZES PRODUCED BY THE DIFFERENT SEED SIZE GROUPS

Year	1946	1947	
Lot		No. 72	No. 73
A	0.58	0.31	0.34
B	0.48	0.35	0.33
C	0.52	0.31	0.32
D	0.45	0.33	0.34
E	0.54	0.42	0.32

The coefficients clearly show no correlation with seed-size groups.

Thus, it may be concluded that size of seed has no effect either directly, as a result of differences in mean size (as shown in Parts I and II) or indirectly, as a result of lack of uniformity within the seed-size group, on the uniformity in size of roots in the whole field.

DISCUSSION

The qualities of promptness in germination, uniformity in size and uniformity in shape are all of importance to the grower of turnips. These qualities have been studied using registered seed of the Laurentian variety, screened to provide five fractions of different mean size, during the growing seasons of 1946 and 1947, in order to determine whether size of seed is a significant factor influencing these qualities.

No significant differences were found in laboratory determinations of germination speed of, or in the field, of mean size of roots produced from, seeds of different mean size, nor was there any difference in uniformity of root size among the different seed-size groups. The smallest seed group, however, produced significantly flatter shaped roots in the 1947 trials, but in the 1946 trials, the effect, while apparent, could not be stated to be significant.

The failure of the smallest size of seed to produce a satisfactory stand in the 1947 trials at Sackville, which was also experienced in the Macdonald College trials,* in spite of a high laboratory germination is also a factor which must be considered. This, with the fact of significantly different root shape suggests that material which goes through a 1/18 screen should be removed from seed stock. The removal of this fraction would involve a loss of about 1–1½ per cent by weight, if the samples used in this investigation are typical of Laurentian stock; a loss that might be considered negligible. Since these seeds are very small compared to seeds of the larger fractions, their retention would have a disproportionally great effect on field stand and root type, 1–1½ per cent by weight corresponding to 2–3 per cent by number. Of course, this is a very small proportion of the plants in the field and at thinning time, since this fraction is harder to establish, it is likely that it would be represented in still smaller proportion. However, the point chosen (seed passing through a 1/18 screen) may not be the most suitable and it is possible that, for example, seed passing through a 1/17 screen should be removed.

Further study would be needed to determine how uniform the Laurentian variety is in size of seed and in the proportions of seeds of different mean sizes when grown in different years and in different places, and whether it would be safe to make a sweeping statement that all seed smaller than a certain size should be removed. It is believed, however, that it is safe to recommend the removal of all seed that goes through a 1/18 screen since such seed may be considered abnormally small for any swede stock.

* Communication from L. C. Raymond.

SUMMARY

Seed of swede turnips of the Laurentian variety was screened into five fractions of different mean sizes which were tested in the laboratory for germination speed and germination capacity and in the field for yield, shape and uniformity of roots. Seeds of small size were in general as prompt to germinate and of as high germination capacity as seeds of large size, but failed to give as good a stand in the field in some plots. Roots produced by the smallest size of seed tended to be flatter in shape than those produced by the larger sizes, but did not differ significantly from the latter in mean size nor in uniformity of size. Owing to the difference in shape of the roots produced by seeds of the smaller sizes and their failure to become satisfactorily established in the field, it is recommended that the smallest size group be removed from seed stock.

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A STUDY OF NUTRITIONAL ANEMIA IN SUCKLING PIGS

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Since the demonstration by McGowan and Crichton in 1923 (11) that anemia in suckling pigs is due to a deficiency of iron in milk, practicable methods of treatment have been introduced which have greatly reduced, but have by no means eliminated, losses attributable to this disease. Undoubtedly further progress toward the elimination of swine losses from this source can be achieved by continued instruction of swine producers in the use of currently recommended preventive treatments, but recent evidence raises the possibility that these recommendations may not be adequate in all cases.

Apart from the discovery of the importance of copper in hemoglobin formation by Hart and co-workers (6), anti-anemia value under various conditions and in diverse species, has been attributed to numerous compounds including glutamic acid, arginine, lysine, pantothenic acid, pyridoxine, ascorbic acid, niacin and folic acid. Of these, only pyridoxine and folic acid have been associated with swine anemia. Hughes and Squibb (9), Wintrobe *et al.* (19) and Cartwright, Wintrobe and Humphreys (2) demonstrated the erythropoietic action of pyridoxine in pigs maintained on an artificial ration, while Cunha and associates found that folic acid stimulated hemoglobin formation to some extent in growing pigs receiving a purified diet (3, 4). In addition, folic acid has been shown to be essential in the formation of hemoglobin in the chick (8) and to be of value in the treatment of some cases of pernicious and nutritional macrocytic anemia in humans (17). That this vitamin might have some importance in the treatment of the anemias of suckling animals is suggested by the knowledge that cow's milk is a poor source of folic acid (1). However, Johnson, James and Krider (10) raised pigs from birth to eight weeks of age on "synthetic milk" lacking in folic acid, without producing consistent deficiency symptoms even when a bacteriostatic agent was employed.

Some of the data in the present paper were obtained from experiments conducted to study the influence of age at the time of initial dosage on the efficacy of the reduced iron method of treating anemia in suckling pigs. Blood hemoglobin levels are also reported for pigs maintained under practical conditions and treated with reduced iron plus either copper, pyridoxine, folic acid, or pyridoxine and folic acid. Limited data are included on hemoglobin levels recorded for suckling pigs allowed access to pasture.

EXPERIMENTAL

Investigations were conducted at the University of Alberta from 1946 to 1948 to obtain information concerning the comparative value of several treatments for nutritional anemia in suckling pigs. All pigs were farrowed by sows receiving a gestation-lactation ration of equal parts oats and barley, with pasture in season, and either 6 per cent or 12 per cent mixed protein-mineral supplement depending upon the availability of pasture.

Unless otherwise designated, all litters were retained indoors in pens with concrete floors and wooden sleeping platforms during the course of the experiment.

Treatments

I. Reduced iron

Hart (7) has denoted a level of 175 mg. of iron per week as sufficient to meet the needs of suckling pigs and this figure has been widely accepted. Reduced iron, which was introduced as a practical treatment for swine anemia by Schofield (14), was administered in these experiments at the rate of 210 mg. per week in a single dose. In order to increase the accuracy of administration, the reduced iron was mixed with dextrose to provide 210 mg. of reduced iron per gram of mixture. One gram of this mixture was weighed into a small envelope from which it was deposited on the back of the pig's tongue. The importance of age at the time of initial treatment was studied by beginning weekly therapy at the following ages: (a) 1 day (b) 3 days (c) 4-6 days (d) 8 days. Littermate controls were maintained in all groups except those receiving treatment (c).

II. Reduced iron plus copper sulphate

Copper sulphate was added to the reduced iron and dextrose mixture described under Treatment I at a rate calculated to provide 35 mg. copper per week (7). The pigs were treated weekly beginning at one day of age and littermate checks were maintained on reduced iron alone.

III. Vitamin treatments

(*a*) Reduced iron plus 10 mg. folic acid per week.
(*b*) Reduced iron plus 25 mg. folic acid per week.
(*c*) Reduced iron plus 30 mg. pyridoxine per week.
(*d*) Reduced iron plus 10 mg. folic acid plus 30 mg. pyridoxine per week.

The vitamins were administered five times per week in powder form with a dextrose base beginning at 4-6 days of age. Iron was given at weekly intervals to the test pigs and their littermate controls beginning at the first day of vitamin supplementation.

IV. Pasture

Limited observations were made on the value of giving pigs access to pasture at 11 days of age. Others were turned on pasture at 22 days of age after having been treated with iron or iron and copper.

Blood Samples

Blood obtained from a marginal ear vein was measured in a 20 cu. mm. hemoglobin pipette. The hemoglobin values were determined by the method of Evelyn (5) using an Evelyn photoelectric colorimeter.

RESULTS AND DISCUSSION

Iron Treatments

The hemoglobin values obtained for the iron-treated pigs are shown graphically in Figure 1.

From the results shown in Figure 1 it is apparent that the age at which the iron treatment was begun was an important factor in determining the degree of success attained in combating anemia in these suckling pigs.

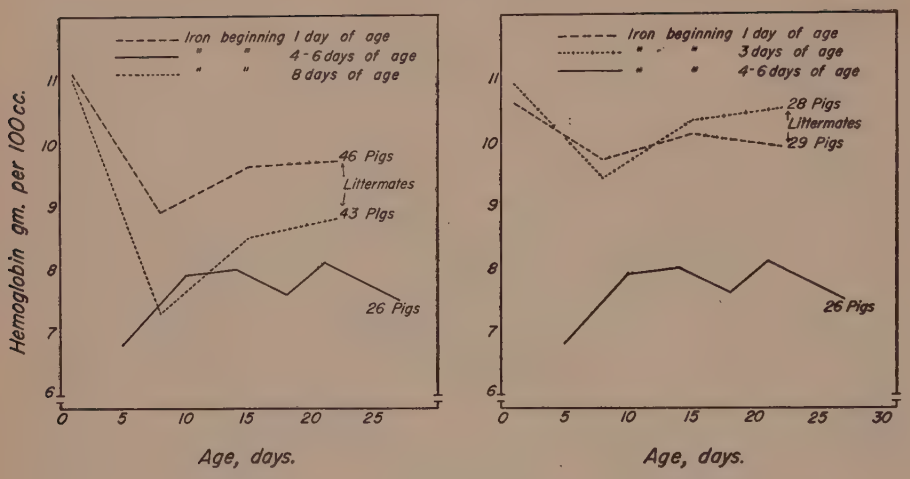

FIGURE 1. The importance of age at the time of initial treatment for anemia.

The average values obtained for the pigs treated initially at 4-6 days of age represent a condition of moderate anemia, whereas those for the animals dosed at one or three days show a satisfactory hemoglobin level. Several of the pigs in the group treated at 4-6 days remained acutely anemic, even after reduced iron therapy. The hemoglobin picture for those treated at 8 days resembles that of the pigs dosed at 4-6 days, but appears to be slightly more favorable at about three weeks of age. This difference may be attributable to inter-litter variation which is known to be extensive (15).

It has long been recognized that blood hemoglobin may fall to a dangerous level within a few days after birth, and mainly for this reason a number of investigators (14, 18, 16, 13) have recommended early treatment. It would appear, however, that this aspect of swine anemia control has not been sufficiently emphasized, since a number of current recommendations still call for treatment beginning at one week of age. The results summarized in Figure 1 show that when therapy is postponed beyond the third day, there is not only a rapid initial decline in hemoglobin levels, but in addition the level attained after treatment may, for a period of at least two to three weeks, remain well below that of pigs treated within 3 days of birth.

Iron and Copper Treatment

The hemoglobin values of 31 twenty-two-day-old pigs treated with reduced iron and copper sulphate averaged 10.8 gm. per 100 cc. of blood while those of 36 littermates receiving only reduced iron averaged 10.7 gm., indicating that the pigs were not deficient in copper.

Vitamin Treatments

From the results summarized in Figure 2 it is obvious that, at the levels employed in these experiments, neither folic acid nor pyridoxine, either singly or in combination, was effective in increasing the hemoglobin content of the blood of suckling pigs treated with reduced iron. Results obtained with six pigs dosed with folic acid at the rate of 25 mg. per week suggest that at this high level folic acid may have a depressing effect on the rate of hemoglobin formation, particularly during the first three or four weeks.

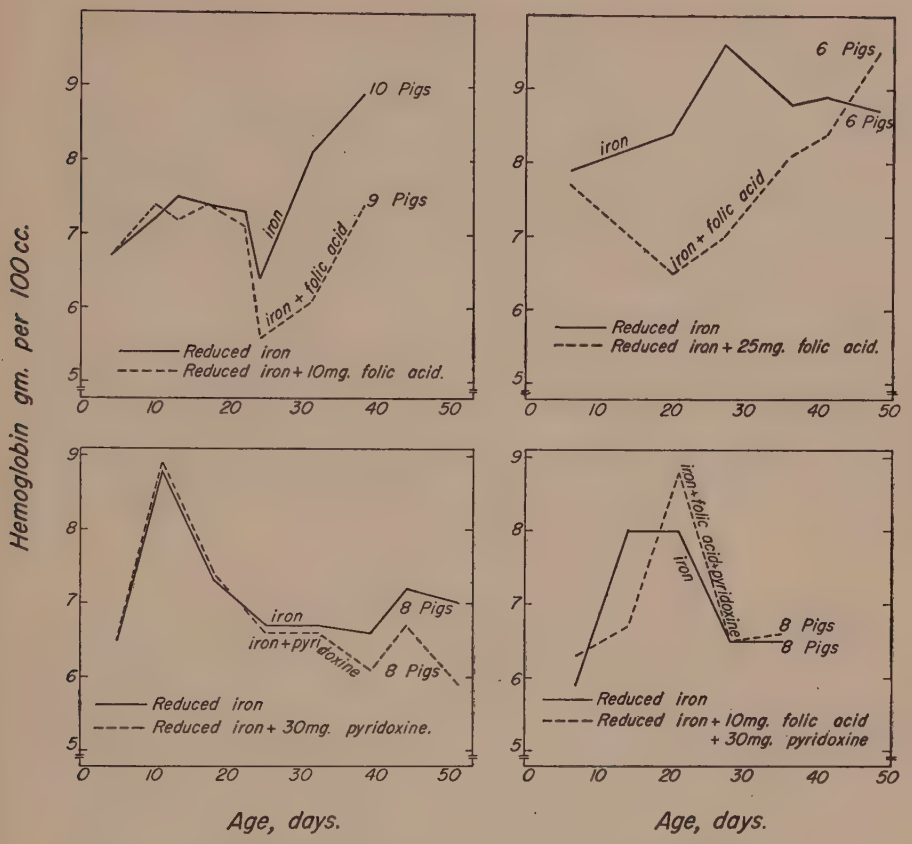

FIGURE 2. The effect of treating littermate pigs with reduced iron vs. reduced iron plus folic acid* and/or pyridoxine on the hemoglobin content of the blood. Vitamin levels indicated are on a weekly basis.

*Folic acid was supplied by Lederle Laboratories, Pearl River, N.Y., through the courtesy of E. L. R. Stokstad.

Pasture Treatment

Litter 201Z was placed on pasture at 11 days of age with no previous treatment for anemia. As shown in Table 1, a spontaneous regeneration of hemoglobin occurred in all pigs.

TABLE 1.—THE EFFECT ON THE HEMOGLOBIN LEVEL OF GIVING PIGS ACCESS TO PASTURE

Pig No.	Age, days		
	11	14	17
1	5.4	7.8	10.2
2	6.3	7.8	9.3
3	6.3	8.1	9.2
4	6.8	8.3	9.2
5	5.3	8.4	9.6
6	5.1	8.0	9.0
7	5.4	7.9	9.8
8	5.0	7.9	8.3
Average	5.7	8.0	9.3

The satisfactory response obtained from giving young pigs access to pasture suggests that this may be the safest means of protecting them from anemia. The resulting increase of 63 per cent in the hemoglobin level over six days is in sharp contrast to the increases of 18 per cent and 16 per cent obtained over a comparable period following iron treatment at 4-6 or 8 days of age respectively (see Figure 1). One hundred and thirty-eight 22-day-old pigs having a previous history of iron or iron and copper treatment, which were turned on pasture with an average hemoglobin reading of 10.02 gm., underwent a mean increase of .63 gm. or 6.3 per cent in four days.

Hemoglobin Levels at Birth

An average hemoglobin value of 10.84 gm. was found among 208 pigs tested within 24 hours of birth. These were comprised of equal numbers of males and females, the mean for the males being 10.70 gm. and for the females 10.97 gm. With respect to the observation of Mitchell (12) that suckling female rats possess a greater resistance to anemia than males, it is interesting to note that no such difference was found in the present study with pigs.

SUMMARY AND CONCLUSIONS

Experiments are described in which it was observed that the hemoglobin content of the blood of suckling pigs treated with reduced iron at weekly intervals beginning at 1 to 3 days of age, remained appreciably higher over a period of three weeks than that of comparable pigs treated initially at either 4 to 6 or 8 days of age. These results emphasize the importance of initiating iron treatment on or before the third day following birth. Pigs treated with commercial reduced iron did not show any additional response from supplementary copper. Likewise, hematopoiesis was not accelerated by additions of folic acid or pyridoxine. The rate of hemoglobin regeneration in anemic pigs given access to pasture was significantly greater than in those treated with reduced iron.

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MINOR ELEMENT DEFICIENCIES AFFECTING CANADIAN CROP PRODUCTION[1]

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An increase in the prevalence of minor element deficiencies may be expected as the pressure of increased population compels more extensive land use and perhaps the use of poorer sub-marginal soils. To attain higher production greater use is being made of commercial fertilizer and while this may be a desirable practice it results in a heavier drain upon nutrients not supplied in the fertilizers. Unless especial attention is paid to soil management higher production may result in humus depletion and humus is an appreciable source of the minor elements essential for plant growth. While the more obvious occurrences of minor element deficiencies in Canada have been diagnosed and fairly satisfactory control measures established, there may be a much more extensive decrease in production arising from such factors, unsuspected because not associated with marked abnormal plant growth symptoms.

BORON

Apples

Working independently, McLarty (30) in British Columbia, Hill and Davis (15) in Ontario and Quebec, and Young (38) in New Brunswick associated physiological disorders of the apple known as drought spot, internal cork and corky core with a deficiency of boron. Although this association was not determined until 1936 these disorders had been recorded in various fruit-growing areas for a number of years, increasing in severity and economic importance from 1921 to 1935. McLarty and Wilcox (31) recommended broadcasting boric acid crystals at the rate of eight ounces per tree over a circular area at least twenty feet in diameter around each tree to be treated. Hill and Davis (15) showed that, common with other boron deficiency diseases, these disorders are influenced by high lime and nitrogen content of the soil, and Davis (7) later gave control recommendations as follows: "Cork disorders may be corrected by boron application to the soil at the rate of four to eight ounces of borax per tree, applied in spring and worked into the soil if possible. If the soil is alkaline or on the high lime side immediate results may be obtained by incorporating borax with the regular lime sulphur sprays. If this is done two applications should be sufficient, one at the time of the calyx spray and the other, the second spray after that using borax at the rate of $2\frac{1}{2}$ pounds to 100 gallons of spray mixture." In 1937 Middleton and McLarty (36) advocated treatment of all orchard land in the Okanagan and Kootenay valleys of British Columbia with boric acid at the rate of thirty pounds per acre. Apple trees which have not been affected should be treated as a preventive measure; but trees which received boron during the previous season should not be treated again for some years. In 1939 traces of corky core and drought spot were found on a few trees treated with one-half pound boric acid in 1936, and McLarty (32) accordingly recommended that a second application

[1] Contribution No. 707 from the Division of Horticulture, Experimental Farms Service, Ottawa.

be made in the autumn of 1939 to orchards treated in 1936. Up until 1940 about two-thirds (15,000 acres) of the British Columbia orchard land had been treated. McLarty also recognized five symptomatic diseases of apples due to boron deficiency, namely, corky core, drought spot, flat fruit, measles and die back. Eaves and Hill (18) also reported that a single treatment, applied as a soil treatment or a spray, proved effective for a period of three years.

While boron deficiency in apples had not been so prevalent in Nova Scotia (23) as in other areas it occurred fairly frequently in individual trees or small groups of trees and recommendations have been made for its use as a preventive measure.

It will be seen that boron deficiency of apples is of major economic importance in all the main fruit-growing areas.

In British Columbia the present control recommendations are to apply a soil application of boric acid every third year at the rate of thirty pounds per acre. In the provinces of Nova Scotia and New Brunswick use is made of a 9-5-7 fertilizer containing four per cent commercial borax to be employed every third or fourth year. In the province of Quebec boron is applied as a foliage spray adding $2\frac{1}{2}$ pounds of borax to 100 gallons of regular lime sulphur or mild sulphur spray mixture in the calyx and second cover spray. Recommendation for treatment is made through the spray service calendar every third year, and this serves as a convenient manner of maintaining the necessary boron supply without the possibility of creating an excess.

In Ontario many of the orchards previously affected with boron deficiency are located on alkaline soils. On such soils effective control may not always be obtained by soil application in a season when very low soil moisture conditions exist. For this reason greater use is made of the foliage spray treatment.

Other Fruits

It is only in the province of British Columbia that boron deficiency has been definitely identified on fruits other than the apple. In 1941 McLarty (33) stated: "In respect to the Okanagan district it is now well established that all agricultural land in this district is generally deficient in boron unless it already has received a treatment. Crops which have definitely benefited from such treatment are all orchard trees (apple, pear, peach, apricot, prune and cherry), raspberries, currants, turnips, mangels, beets, alfalfa, sweet clover, celery, spinach, lettuce, wheat and oats."

McLarty (34) also stated that boron deficiency on other fruits is less clearly defined than on the apple and that other factors may cause a condition in the fruit that is similar. The condition in pear fruit that has responded to boron treatment is described as follows: "The calyx end of the fruit is depressed; there is an excess of stone cell development and large cracks may develop on the surface midway between the calyx and stem-end. A roughening of bark tissue which corresponds to the 'measles' on apple twigs also occurs. The dying back of pear twigs in the spring, in the same manner as in the apple, is a reliable symptom of boron deficiency."

Drought spot is sometimes found on cherry and apricot and on plum some gum spotting occurs, but not all has been cured with boron. With the exception of the cherry, stone fruits are as susceptible to die back as

apple or pear. Fitzpatrick and Woodbridge (12) described definite foliage and die back symptoms of boron deficiency in apricots with plants grown in sand culture. Symptoms similar to those described from the plants grown in sand were found in several apricot orchards in the Okanagan Valley in the spring of 1940.

Turnips

The use of boron has become of major economic importance for the control of brown heart or water core in the production of the turnip. In New Brunswick about two-thirds of the 9300 acres in turnips were treated with borax in 1945. In 1947 the approximate tonnage of borax-containing fertilizers for the Maritime Provinces was 3353 tons and straight sales of borax were approximately 20 tons. Experiments in Prince Edward Island indicated that in a normal cropping plan, when turnips come only once in four or five years, they require borax each time they occur in the rotation (22). The Advisory Fertilizer Board for Ontario has also recommended that boron be employed for turnip production.

Turnip brown heart has been under investigation in Canada since 1928, a year when this disease proved to be the direct cause of very considerable losses to farmers in Eastern Canada. McLeod and Howitt (28) demonstrated that borax applied directly in the drill at the rate of ten pounds per acre effected a satisfactory control of this disorder. Hill and Grant (16) studied the symptoms of boron deficiency as exhibited by turnips growing in sand culture and their observations were confirmed and extended by Coulson and Raymond (6). Hurst and MacLeod (22) reported on further tests conducted during 1933-35; 15 to 20 pounds of borax per acre gave satisfactory control on a variety of soils and proven methods of applying the borax were as follows: (a) in the drill; (b) at the sides of the drill; (c) broadcast and (d) combined with the fertilizer. Satisfactory control was also obtained by spraying the required amount of borax on the soil or the foliage of the turnip.

On some nearly neutral soils in the province of Quebec as much as fifty pounds of borax per acre is required to give adequate control of brown heart, while on other slightly acid soils fifteen pounds per acre will suffice.

In New Brunswick, Bailey (1) found borax applications in the drill as low as fifteen pounds per acre and sprays from twenty to eighty pounds per acre gave effective control of brown heart if applied at any time before the roots began to swell. Recommendations for the provinces of Prince Edward Island, Nova Scotia and New Brunswick for 1949 are as follows: A special 3-15-6 or 3-12-10 fertilizer with three per cent commercial borax added; where lime has been applied, add borated mixtures or borax enough to supply fifteen to twenty pounds per acre.

In Ontario spraying or dusting for the prevention of water core is now being used generally (25). This is especially true in the high-lime soil areas where soil applications of borax have failed to give results. The recommended spray ingredients are twelve pounds of powdered borax, three pounds of bentonite clay and one pint of Orthex spreader in forty imperial gallons of water. Forty to fifty gallons of spray should be applied per acre when the diameter of the turnip root is between 1 and $1\frac{1}{2}$ inches.

The recommended dust is finely powdered borax (300 mesh) and Celite (No. 209) mixed in equal proportions by weight.

Alfalfa

In the course of experiments with apples, McLarty (35) found that application of boric acid had a marked effect in improving the colour and growth of the alfalfa cover crop. Subsequently alfalfa yellows was found in a considerable number of fields in British Columbia and McLarty stated that land in alfalfa should receive an application of thirty pounds borax per acre where the alfalfa shows a yellow-top condition and fifteen pounds per acre where the plants remain green as a preventive measure. Although the disorder has been encountered in individual fields in other provinces its incidence has not been so common as to warrant a general recommendation of boron treatment for fields in alfalfa.

Celery

Ferguson and Wright (11) described and illustrated boron deficiency symptoms on celery when grown in sand culture. Browne (34) reported that on mildly acid peat soils celery tends to develop boron deficiency diseases in the third or fourth year of cropping. Occasional applications of fifteen or twenty pounds of borax per acre are therefore recommended on such soil type. In extreme cases quicker results can be obtained by dissolving two or three pounds borax per one hundred gallons in at least two of the celery sprays, applied when the crop is from one-third to one-half grown.

A general recommendation is given for celery growing on muck soils in Ontario and Quebec. On mineral soils it is advised that the need for boron be fully confirmed before application is made and a rate of fifteen to twenty pounds of borax per acre is suggested.

Carrots

In sand culture without boron, Hill (17) found carrots turned yellow around the edges of the leaflets, followed by a distinctive pinkish-to-reddish colouration spreading farther into the leaf. Roots of such plants usually developed longitudinal cracks or splits. Browne (45) found that on mildly acid peat soil longitudinal cracking of carrots was completely controlled by soil applications of twenty pounds of borax per acre when in the control plot 62 per cent of the roots were cracked. In British Columbia Harris (13) obtained a significant increase in yield of carrot roots by borax manuring at the rate of fifty pounds per acre though the crop without borax showed no sign of disease.

Other Crops

Boron deficiency of other crops has been of isolated rather than general occurrence.

In sand cultures with tomato, Hill (18) described both foliage and fruit symptoms due to lack of boron which was later confirmed by Ferguson and Wright (11). Ferguson and Wright (11) also produced and described boron deficiency symptoms in cauliflower, cabbage and corn when grown in sand culture, and by the same method Hill (17) described boron deficiency in beet, spinach, carrot and garden pea. Leggatt (24) has reported abnormal germination of pea seeds which appeared perfectly normal but which were grown in a boron-deficient soil area in British Columbia. The addition of boron completely overcame the special type of abnormal sprouts.

COPPER

Up until the present time in Canada, a need for and response to copper application has been established only for certain crops produced on peat or muck soils. Browne (5) states: "Copper is essential in the fertilizer application for onions, carrots, lettuce and spinach. It is probably necessary for potatoes, but since in normal spraying or dusting comparatively large quantities of copper sulphate are used a deficiency with this crop is not likely to occur. Onions appear to need more copper than the spray residue from a previous potato crop and also respond to copper on neutral or alkaline mucks. The application of copper on onions improves skin quality and increases yield. In general the application of 50 to 100 pounds of copper sulphate per acre is sufficient." The Ontario Fertilizer Advisory Board also recommends the use of copper for such crops on peat or muck soils.

COBALT

Soil cobalt deficiency appears to have a primary effect on the health of animals feeding on the crops thereon produced, rather than on the general vigour and growth of plants. In Canada widespread cases of animal malnutrition due to cobalt deficiency have not been established though a deficiency is suspected in certain areas.

Bowstead and Sackville, (2) of the University of Alberta, describe the value of various supplements in combating an unthrifty condition of sheep which developed when they were maintained on a basal diet of non-leguminous hay and ground oats. Certain ewes were given a cobalt supplement equivalent to five milligrams of cobalt daily. There followed a rapid increase in weight and improvement in thrift. Analyses indicated that the non-leguminous hay produced in the area was very low in cobalt. Subsequent studies confirmed these findings.

Soils from Cape Breton County, Nova Scotia, where a deficiency of cobalt was suspected, were analysed. The soils suspected of cobalt deficiency showed a total content of 2·7 p.p.m., while that representing an area considered to be satisfactory showed 8·9 p.p.m.

IRON

Iron deficiency encountered is of the lime-induced chlorosis type. It constitutes a serious problem on high carbonate alkaline soils of the three Prairie Provinces, Manitoba, Saskatchewan and Alberta, in the production of fruit, ornamental shrubs and shade trees. Control measures so far employed have been only partially satisfactory and temporary in nature. Direct injection of powdered iron salts, ferrous sulphate, ferric citrate, etc., have been proved more satisfactory than soil applications or foliage sprays. In 1947 a special committee was formed to study this problem. It was considered that soil amendments have application in certain restricted areas where the deficiency symptoms are not severe. It was felt that probably the most hopeful approach was through the question of varietal resistance. In the case of plants that are budded or grafted this might involve rootstock resistance and would involve a breeding programme with the purpose of breeding and propagating rootstocks definitely resistant to lime-induced iron deficiency.

MANGANESE

A deficiency or response to manganese has only been reported in isolated instances, occurring on calcareous, alkaline soils.

In the Horticultural Division of the Experimental Farms Service at Ottawa manganese deficiency has occurred on soya beans on an alkaline soil. Good control was obtained by spraying the foliage with one per cent manganese sulphate. Harris (14) in British Columbia has shown that, on a glaciated sandy loam upland soil, the addition of manganese significantly increased yield, total carbohydrates and vitamin C with the Cuthbert variety of raspberry.

Since 1923 certain areas at the Central Experimental Farm at Ottawa have been known as "sick soil areas" and oat plants grown on this area showed symptoms of grey speck. Timonin (37) has reported on soil studies in this connection. It was determined that a susceptible variety of oats harboured in its rhizosphere a denser population of manganese-oxidizing, casein hydrolyzing and denitrifying bacteria than the rhizosphere of a resistant variety. On application of soil fumigants such as chloropicrin cynogas and formaldehyde the bacteria capable of oxidizing manganese were reduced or eliminated. The plants grown in such treated soil were free from symptoms of manganese deficiency. The application of 190 pounds per acre of commercial calcium cyanamid resulted in practical control.

McLachlan (26) showed that chlorotic oats growing on a localized area at the Ontario Agricultural College, Guelph, were caused by manganese deficiency and that the condition was remedied by spraying with a one per cent solution of manganese sulphate with bentonite and soap added as a sticker and spreader; soil applications however, gave only minor response. The cause was apparently biological in nature since bacteria were isolated which actively converted $MnSO_4$ to the oxide form in vitro. He later (27) noted that the addition of sulphur at one thousand pounds per acre increased the yield and in one instance reduced the amount of manganese necessary as a soil application by about two-thirds. The application of a two per cent spray of manganese sulphate with a sticker spreader produced good control. Browne (4, 5) has shown that on a muck soil the quality of celery can be improved by applications of manganese sulphate up to fifty pounds per acre.

ZINC

Zinc deficiency has not yet been observed or identified in Canada. It occurs in the State of Washington, bordering British Columbia, and it is strongly suspected that it exists in some parts of the Southern Okanagan in British Columbia.

MOLYBDENUM

Molybdenum deficiency has not yet been observed or diagnosed in Canada.

MAGNESIUM

Although magnesium may not be considered as a minor element it is not generally directly applied as a regular fertilizer.

Its importance in quality tobacco production in Canada, however, has been fully recognized. Horton (21) reported the occurrence of sand drown in the New Belt and associated it with low available magnesium content of the soil. McEvoy (29) has published the optimum nutrient requirements for tobacco. Fertilizer recommendations have taken this need into account and are as follows in respect to magnesium: Owing to the frequent occurrence of magnesium deficiency or "sand drown" it is recommended that a high grade dolomitic limestone, containing at least 19 per cent MgO, be used as a filler in all tobacco fertilizers. For cigar tobacco it is noted that the addition of 2 per cent MgO to the fertilizer mixture tends to improve the quality of cigar tobacco.

Magnesium deficiency is of considerable importance in potato production in the Maritime Provinces. Magnesium deficiency in New Brunswick was first noticed in 1924 and gradually increased until in 1933 it had become a limiting factor in potato production (9). Co-operative experiments conducted by the Fredericton Laboratory of Plant Pathology and the New Brunswick Department of Agriculture showed that the application to the soil of 75 to 150 pounds of dolomitic lime or 60 to 120 pounds of magnesium sulphate per acre corrected the trouble. Spraying the growing crop with similar amounts of magnesium sulphate in solution also cured this disease. Magnesium deficiency was very prevalent in Prince Edward Island in 1943, being due to one or more of the following factors: high soil acidity; heavy applications of acid-forming fertilizers containing no magnesium; low organic matter content of the soil. Fields that received an application of Bordeaux mixture containing ten pounds of magnesium sulphate in eighty gallons showed a marked improvement and three applications completely cured the trouble. Increased yields were also obtained by applying thirty pounds per acre of magnesium oxide mixed with the 4-8-10 fertilizer.

After subsequent experiments the Maritime Fertilizer Council have recommended that for potatoes on very acid solids a fertilizer mixture such as a 5-10-13, 5-10-10 or 6-9-12 with one per cent added MgO should be employed.

In 1938 Hill (19) described and diagnosed magnesium deficiency occurring in severe form in an apple orchard area in the province of Quebec. Since that time it has occurred in this district in individual orchards with varying severity from year to year and has also occurred in individual orchards in Ontario and Nova Scotia. Hill and Johnston (20) later described magnesium deficiency symptoms of the apple as occurring in sand culture and in commercial orchards. Field experiments have shown that effective response to surface broadcast applications of magnesium sulphate on bearing sod orchards may be delayed for a period of two to three years and the content in the foliage is likely to drop below requirements within a subsequent period of two years. Three to four cover sprays of two per cent magnesium sulphate were effective in correcting magnesium deficiency in the year of application. This treatment is recommended as a quick, temporary control measure. Although the magnesium content of the foliage was satisfactorily increased in the same season of treatment the effect was sometimes not carried over even to the next growing season. Magnesium deficiency affecting the apple has been generally encountered on strongly acid soils. It was found that an application of 50 to 75 pounds of dolomitic

limestone spread around each tree effectively increased the magnesium content of the foliage the third year after application. It is recommended that an application of dolomitic limestone be made on such soils and that during that period before the limestone application is effective, immediate but temporary control be obtained by foliage sprays.

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RESULTS OF STUDIES OF CRESTED WHEATGRASS[1]

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INTRODUCTION

The Dominion Range Experiment Station, Manyberries, Alberta, is located in an area which is representative of nearly 8,000,000 acres of land unsuitable for production of annual crops. Lack of moisture and the high rate of evaporation are the principal factors limiting growth throughout the area. Attempts to produce wheat, oats, and other annual cereals have been generally unsuccessful. It is recognized now that a type of agriculture, based on the utilization of native and cultivated grasses, is the best land use practice for the region.

The Manyberries Station was established in 1927 to investigate the problems of land and grass use in the dry section of the Prairie Provinces. One of the most important problems at that time, and equally so at present, was to maintain the grazing capacity. Experiments were started to investigate the relationship between this factor, grazing practices, range management, water development, feed reserves, land use, and the utilization of native and cultivated grasses. Many of the results have been recorded in Results of Experiments, 1927-1936, inclusive (5). This paper deals in a general way with the results of crested wheatgrass reseeding experiments on abandoned farm land and depleted native pasture.

PHYSICAL FEATURES

The greater part of the region represented by the Station is from flat to gently rolling. In places the prairie is deeply cut by "coulees", steep-banked eroded water courses which are dry most of the year. Where erosion has been most severe, "badlands" have formed. These areas are sparsely, if at all, vegetated due to the constant action by wind and water. Drainage is largely into sloughs, although the local drainage basin is a part of the Milk River system, which in turn flows into the Missouri River.

The soils of the area are mainly light loams. The profile is associated with the residual rock formations which, in this case, are principally Bearpaw and Belly River shales. Practically all of the area has a solonized profile, with characteristic eroded pits due to the patchy removal of the "A" or surface horizon. These eroded pits may or may not support vegetation. The exposed "B_1" horizon is usually dark in colour and very hard, thus preventing or limiting water penetration into the subsoil.

Table 1 shows the fertility of the soil in the Manyberries district.

The climate of the area is marked by low precipitation, a high rate of evaporation, great extremes of temperature, frequent high winds, and abundant sunshine. In Table 2 a summary of the climatic information for the Station is presented.

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TABLE 1.—SOIL NUTRIENTS FOUND IN THE LIGHT LOAMS OF THE DOMINION RANGE EXPERIMENT STATION, MANYBERRIES, ALBERTA

Depth	Horizon	Total N.	Total P.	Calcium	Magnesium	pH	P. p.p.m.
0 – 5″	A_1	0.108	0.035	0.39	0.25	6.1	17
5 – 7″	A_2	0.060	0.027	0.44	0.28	7.1	12
7 – 12″	B_1	0.111	0.290	0.48	0.82	8.3	25
12 – 18″	B_2	0.086	0.037	1.29	0.85	8.7	78
At 20″	C	0.066	0.059	0.50	0.86	8.4	44

(Courtesy, Survey of Milk River Sheet, by F. A. Wyatt, J. D. Newton *et al.*, University of Alberta.)

It will be noted in the table that the total annual precipitation is only 11.31 inches, and the precipitation : evaporation ratio is 0.27. This factor is the principal climatic condition limiting plant growth. While an average annual snowfall of 34.12 inches may appear high, it does not remain throughout the winter because of the many warm "chinook" winds which melt the snow, often as soon as it falls.

The vegetational cover is classified as short-grass prairie (1), and is characterized by the dominance of blue grama grass, *Bouteloua gracilis* (H.B.K.) Lag., which comprises over one-third of the total vegetative cover, and common spear grass, *Stipa comata* Trin. and Rupr. Other important grasses are western wheat grass, *Agropyron Smithii* Rydb., Junegrass, *Koeleria cristata* (L.) Pers., and dwarf bluegrass, *Poa secunda* Presl. Involute leaved sedge, *Carex eleocharis* Bailey is abundant, while nigger wool, *Carex filifolia* Nutt. is of frequent occurrence. Common broad leaved plants include pasture sage, *Artemisia frigida* Willd., dwarf phlox, *Phlox Hoodii* Richards, broom weed, *Gutierrezia diversifolia* Greene, winter fat, *Eurotia lanata* (Pursh.) Moq., salt sage, *Atriplex Nuttallii* S. Wat., and hoary sage bush, *Artemisia cana* Pursh., cactus, *Opuntia polyacantha* Haw., is very common at local points. Little club moss, *Selaginella densa* Rydb., is very abundant over all of the area. Its effect on the native vegetation is still a debatable question. Some authorities credit it with little or no influence on the vegetation, while others feel it stunts the growth of surrounding plants. In general, the vegetation is highly nutritive and palatable, but is of low productivity. The combined cover of all grass species is usually less than 10 per cent, but forbs and weeds increase the total vegetational cover from 20 to 35 per cent.

ECOLOGY OF CRESTED WHEATGRASS

The grass most highly recommended for reseeding in the area represented by the Manyberries Station is crested wheatgrass, *Agropyron cristatum* Gaertn. This grass, a native of the Steppe region of European Russia and Southwestern Siberia, was introduced into the United States in 1898. It did not attract much attention until after 1915 when its adaptability to cool, dry areas was observed. About this time the University of Saskatchewan obtained a small amount of seed. Small experimental plots were started and were the beginning of a crested wheatgrass seed industry that was the source of seed used to sow abandoned farm lands after 1935 in Western Canada.

TABLE 2.—METEOROLOGICAL RECORDS—DOMINION RANGE EXPERIMENT STATION, MANYBERRIES, ALBERTA

1929-1947 (19 years)

Month	Temperature F.			Precipitation			Bright sun (hours)	Wind velocity (hourly) 12 year av.	Evaporation (in.)
	Highest	Lowest	Mean	Rain (in.)	Snow (in.)	Total precip. (in.)			
January	61	−44	11.7	0.00	5.56	0.56	99.7	11.3	—
February	67	−45	13.5	0.00	4.15	0.42	122.8	12.0	—
March	73	−27	26.0	0.10	6.39	0.74	145.2	11.8	—
April	90	−15	42.4	0.63	2.91	0.92	195.6	12.8	—
May	94	12	52.7	1.23	0.08	1.24	251.7	12.1	5.54
June	105	30	59.7	2.44	0.00	2.44	247.6	10.9	6.42
July	103	34	69.0	1.31	0.00	1.31	341.0	9.2	8.31
August	104	17	65.8	0.75	0.00	0.75	300.7	10.0	7.01
September	96	10	54.4	1.01	1.31	1.14	194.5	10.3	4.33
October	91	−11	44.2	0.40	2.59	0.66	163.0	10.9	—
November	70	−26	26.7	0.02	5.72	0.59	110.4	10.7	—
December	63	−32	17.9	0.00	5.41	0.54	92.6	11.3	—
Annual	—	—	40.3	7.89	34.12	11.31	2,264.8	11.1	31.61

FIGURE 1. Site 2—Sheep grazing on crested wheatgrass sown during April, 1932.

Crested wheatgrass is a perennial. Its longevity is well illustrated by the seedlings made at the Northern Great Plains Field Station, Mandan, N.D., in 1915. As Westover and Rogler (1947) pointed out, the fifth highest yield over the 33-year period of growth was in 1942, the twenty-seventh year of production. The highest yield was in 1916, production being 3,550 pounds of hay per acre. The lowest, 146 pounds, was produced during the severe drought year of 1936. The average yield for 30 consecutive years has been 1,675 pounds. This is similar to the findings of the North Montana Branch Experiment Station, Havre, Montana, and at the University of Saskatchewan (2). From the evidence of these old stands, it seems feasible that most stands would yield well for 20 to 25 years. What is more important is the fact that even the poorest yields are far greater than those of the native vegetation in a corresponding year. The yields quoted from Havre, Saskatchewan, and Mandan are much higher than those obtained at the Manyberries Station.

Crested wheatgrass is well adapted to an extreme climate. During the 30 years it has been growing at the University of Saskatchewan, and the 20 years at the Manyberries Station, there has never been evidence of any frost damage or winterkilling, even with temperatures as low as 40° to 50° F. below zero.

Crested wheatgrass is drought tolerant; it endures long periods of drought without permanent damage. This ability is credited in part to its very extensive root system, which is able to get moisture from the soil when other less hardy grasses would perish (3). During long periods of summer drought, it becomes dormant and thus is able to avoid serious drought injury. As soon as moisture is available, the grass begins to grow and produce nutritious forage.

Crested wheatgrass is an excellent weed competitor. This is well illustrated by old experiments carried out at the Station, where seedings were made on land covered with annual weeds. Even when the grass was planted in 3-foot rows, the weeds were completely controlled within a few years of planting.

EXPERIMENTAL

Reseeding on Abandoned Dryland

As reseeding represents an important part in any range management program, several varieties of grasses and legumes were obtained and seeded as part of the Range Management Program at the Manyberries Station. Reseeding experiments were established on both native sod and on abandoned farm land in various stages of regression. Different rates of seeding and different cultural treatments were used. The first observations made of these seedings recorded the superiority of crested wheatgrass over all other species. By the time the several seedings were studied in 1948, only crested wheatgrass persisted of the several species seeded, and thus is the only species discussed in this article.

Site 1 is an abandoned field located approximately four miles southwest of the Station. It is a 70-acre field that had been abandoned prior to 1928, and had grown up to weeds, consisting of Russian thistle, *Salsola pestifer* A. Nels., pasture sage, *Artemisia frigida* Willd., tumbling mustard, *Sisymbirium altissimum* L., wild barley, *Hordeum jubatum* L., dwarf plantain, *Plantago Purshii* R. & S., blue bur, *Lappula echinata* Gilib., and gum weed, *Grindilia perennis* A. Nels. The area surrounding this site is typical short-grass prairie dominated by *Bouteloua gracilis* and *Stipa comata*. In November of 1928, the area was seeded to equal sized plots of the following grasses: slender wheatgrass, *Agropyron trachycaulum* var. *typicum*, crested wheatgrass, blue joint, *Agropyron Smithii*, and brome grass, *Bromus inermis*. Of these species the only one surviving in 1948 was the crested wheatgrass. It had been broadcast at 16 pounds to the acre and then single disked. Half of the area seeded to crested wheatgrass was fenced off to prevent grazing. The other half has been heavily spring grazed since it was planted. In 1948, the area had only been lightly grazed and the exclosure, of course, had not been touched. Both areas were point sampled and plots were clipped during the summer of 1948. The results are presented in Table 3.

TABLE 3.—RESULTS OF POINT SAMPLING AND CLIPPINGS ON SITE 1—DENSITY OF VEGETATIVE COVER EXPRESSED AS A PERCENTAGE OF GROUND AREA

	Crested wheatgrass	Stipa comata	Bouteloua gracilis	Koeleria cristata	Poa secunda	Others	Total	Total yield (lb./acre)
Inside exclosure	4.7	0.1	0.2	0.5	0.2	—	5.7	457
Outside exclosure	3.1	1.2	3.0	0.1	3.0	—	7.8	376
Native pasture	—	2.1	3.7	0.8	0.2	1.6*	8.4	300

* 1.0 Per cent is *Agropyron Smithii*, the remaining 0.6 others.

The information presented in Table 3 indicates that, when crested wheatgrass is grazed early in the spring, the native dominants will advance and compete successfully, if a plentiful supply of seed is available. Thus, old stands that are heavily grazed may be invaded by pasture weeds, unless good management practices are followed. However, the crested wheatgrass provided an excellent cover and high quality spring pasture for 20 years, and to-day the grazed area outside the exclosure far outyields the native range on adjacent lands.

Site 2 is located two and one-half miles south of the Station. It was drilled in 6-inch rows during April, 1932, to crested wheatgrass at the rate of 16 pounds per acre. This field has been ploughed and harrowed in August of 1931 after growing a crop of weeds, chiefly Russian thistle and tumbling mustard. The field was protected for one year following seeding, and has been grazed lightly and cut for hay since that date.

Site 2 was point sampled this year, and plots were clipped to estimate yields. The density of crested wheatgrass expressed in per cent was 5.1 per cent, and the yield 359 pounds per acre. At present, there is very little sign of invasion by native grasses. Also there are very few plants of crested wheatgrass that have spread into the native prairie surrounding the reseeded area.

Site 3 is located approximately five miles west of the Station. Part of the field had produced a crop of rye in 1935, whereas the remainder had been abandoned in 1933. Crested wheatgrass was seeded in 1936 using different cultural treatments and different rates of seeding.

On the east side of the field plots were seeded by the broadcast method at the rate of 3 and 6 pounds per acre, on November 2, 1936. One-half of each plot was single disked. Light, scattered stands were produced on all plots. In 1938, meter quadrats were established to study the rate of increase in density of cover. During August of 1940 and 1948, these quadrats were recharted. The information is presented in Table 4.

TABLE 4.—COVERS DETERMINED BY AREA-LIST AND POINT SAMPLING METHOD, AND YIELD FROM CLIPPED QUADRATS ON BROADCAST PLOTS AT SITE 3

	Year sampled	Rate of seeding lb. per acre	Average number plants per sq. meter	Per cent density quadrat method	Per cent density point method	Yield lb./acre air dry
1. Treatment— Broadcast and single disked	1938	1	38	1.50	—	—
		3	23	1.50	—	—
		6	—	—	—	—
	1940	1	48	4.62	—	—
		3	93	5.12	—	—
		6	—	—	—	—
	1948	1	44	4.28	4.9	387
		3	43	4.66	5.1	346
		6	41	4.36	5.0	303
2. Treatment— Broadcast	1938	1	10	0.80	—	—
		3	39	2.02	—	—
		6	21	1.75	—	—
	1940	1	22	4.05	—	—
		3	208	6.72	—	—
		6	148	7.0	—	—
	1948	1	52	6.15	5.2	361
		3	33	4.31	4.6	322
		6	45	4.35	5.1	335

Three widths of row spacing were seeded in April, 1936, west of the broadcast plots. The spacings tested were 6, 12, and 24 inches between rows (Figures 2, 3, and 4).

FIGURE 2. Close drilled crested wheatgrass seeded in 1936—Site 3.

FIGURE 3. Twelve-inch spacing of crested wheatgrass sown in 1936—Site 3.

FIGURE 4 Twenty-four inch spacings of crested wheatgrass sown in 1936. Note the filling in between the rows—Site 3.

FIGURE 5. Crested wheatgrass sown into native sod in background. Notice on the extreme left the dense stand of crested wheatgrass, while native vegetation dominates the plot on the right.

Comparisons of the yields and densities of the different rates of seeding, different cultural treatments, and different row spacings are presented in Table 5.

TABLE 5.—COMPARISON OF YIELDS AND DENSITIES ON SITE 3, 1948

Treatment	Date seeded	1948 density	Yield—lb./acre	
			1940	1948
Drilled 6-inch spacing, 12 lb./acre	April, 1936	5.4	1082	353
Drilled 12-inch spacing, 6 lb./acre	April, 1936	5.3	1054	363
Drilled 24-inch spacing, 3 lb./acre	April, 1936	5.6	736	403
Broadcast—single disk, 6 lb./acre	November, 1936	4.4	—	303
Broadcast—single disk, 3 lb./acre	November, 1936	4.7	—	346
Broadcast—single disk, 1 lb./acre	November, 1936	4.3	—	387
Broadcast—6 lb./acre*	November, 1936	4.3	—	335
Broadcast—3 lb./acre*	November, 1936	4.3	—	322
Broadcast—1 lb./acre*	November, 1936	6.2	—	361
Average		4.9	—	352

* No cultural treatment.

The information in Tables 4 and 5 shows that after a 10-year period a state of equilibrium is reached no matter what cultural practice, seeding method, or rate of seeding is employed, providing there is a favourable seed-bed in which to sow the grass. Under the prevailing climatic conditions, only a certain number of plants will grow, and for each specific year a similar yield can be expected, regardless of rates of seeding or cultural treatments after a stand has been obtained.

In 1940, the plots at Site 3 yielded an average of 1,117 pounds per acre, which high yield is credited to the excellent growing conditions of the season, as well as the youth and vigour of the stand. In 1948, the yields presented in Table 5 are much lower but are not significantly different for either treatment or seeding. During one year of better than average moisture conditions, it is doubtful if the density of the cover would change. However, if improved growth conditions continued for a period of two or more years an increase in stand might be expected. It is interesting to note that the different cultural treatments and the different rates of seeding appear to have no effect on the density or yield of stands produced 12 years after seeding. It may be that this effect is apparent before this length of time has elapsed, but unfortunately no sampling was conducted on any of the areas, and only a few yields were taken prior to 1948. At Mandan, North Dakota, workers have found that thick stands tended to remain thick but the individual plants produced were inclined to be stunted (4).

REGRASSING OF SPRING FLOODED MEADOWS

At Site 4, the benefits of spring flooding were studied. This site is located about eight miles northwest of the Station. It is a heavy clay flat that has been dyked to use the spring run-off. In 1938, a seed bed was prepared and seeded to crested wheatgrass in both 6-inch and 12-inch rows. Table 6 presents the results of the point sampling conducted in 1948.

TABLE 6.—DENSITY AND YIELD OF CRESTED WHEATGRASS STANDS AT SITE 4—AUGUST, 1948

Spacing	Rate, lb. per acre	Date seeded	Density	Yield, lb. per acre
6-inch	12	November, 1938	6.7	1,627
12-inch	6	November, 1938	7.0	1,696
Average	—		6.8	1,661

In comparing the densities of the stands with those of Sites 3 and 4, it will be observed that the density of crested wheatgrass at Site 4 is only increased 39 per cent more than that at Site 3, yet the average yield is increased over 370 per cent. It is interesting to note that at Site 4 the area seeded in 12-inch rows, at the rate of six pounds per acre, had a denser cover (though insignificantly higher), and yielded more than the closer spaced seeding sown at double the rate. Except for the annual rainfall, the only other water this area receives is from the spring run-off which is spread by a dyking system. Thus spring flooding appears to increase the yield many times without greatly increasing the ground cover. Such is a useful grass character for spring flooded projects where, during one out of each three years, there will be either no run-off or insufficient to obtain a satisfactory flooding. When such occurs, crested wheatgrass stands were seldom depleted because of drought, and thus resist the rapid encroachment of pasture and hayland weeds.

RESEEDING ON NATIVE PRAIRIE

An experiment was designed to determine the best method of seeding depleted rangeland to crested wheatgrass. In April, 1938, six treatments were established. These were:

Treatment 1—Single disked and crested wheatgrass broadcast
Treatment 2—Crested wheatgrass broadcast then single disked
Treatment 3—Single disked, crested wheatgrass drilled 6-inch spacing
Treatment 4—Single disked, crested wheatgrass drilled 12-inch spacing
Treatment 5—Crested wheatgrass drilled 6-inch spacing
Treatment 6—Crested wheatgrass drilled 12-inch spacing.

The covers of the treatments were studied by the use of a meter quadrat frame in 1947. The results are listed in Table 7.

Prior to the time of seeding, the site had been overgrazed and was in a badly depleted condition. Annual weeds were beginning to invade the area. Following seeding, grazing was continued but at a much reduced, rate. Because of adverse climatic and ecological conditions, only a very sparse cover of crested wheatgrass is present after nine years. However, the information indicates that the more the ground was worked prior to seeding, which means the killing of native plants, the better the crested wheatgrass cover. Although a stand is being established, it is a very slow process. After eight years, the cover is less than one per cent with the best treatment employed. With a good seed-bed, annual weeds, or stubble, the cover would be from six to eight times greater within a three-year period.

TABLE 7.—PER CENT COVER OF CRESTED WHEATGRASS SEEDED INTO OVERGRAZED NATIVE PASTURE NINE YEARS AFTER SEEDING, 1939-47

Dominion Range Experiment Station, Manyberries, Alberta

	Treatment					
	1	2	3	4	5	6
Number of crested wheatgrass plants	167	72	173	64	25	3
Total surface area sq. cm.	125,000	125,000	125,000	125,000	125,000	125,000
Area covered by crested wheatgrass plants in sq. cm.	1,209	332	771	625	59	37
Crested wheatgrass cover as a percentage of ground area	0.96	0.26	0.61	0.50	0.04	0.03

An interesting observation was made this year at the North Montana Branch Experiment Station, Havre, Montana. During the worst years of the drought, it was decided to try sowing crested wheatgrass directly into the native sod without any previous preparation (Figure 5).

The experiment was started in 1936 and continued till 1940. In 1936, the vigour of the native vegetation was at an exceedingly low ebb, making conditions optimum for the establishment of a stand of crested wheatgrass. As climatic conditions became more favourable for the native vegetation, the stands of crested wheatgrass obtained diminished. The first year of the seeding trial an almost 100 per cent stand was obtained. In 1940, only a few plants of crested wheatgrass were evident. This area has had complete protection from grazing since the experiment was started. The results would seem to indicate that crested wheatgrass may be established on native prairie by simply seeding with a drill, if ecological conditions are favourable to its establishment. These conditions may be brought about by mechanical means such as by using the Noble blade or disking.

In 1938, a field of overgrazed native pasture at the Dominion Experimental Station, Swift Current, Saskatchewan, was drilled in 12-inch rows to crested wheatgrass, at the rate of 8 pounds to the acre. Quadrats were established on this area in 1946. These were charted by the area-list method and have been recharted in 1947 and 1948 by the same method. The results are presented in Table 8.

TABLE 8.—SUMMARY OF QUADRAT INFORMATION FROM 1938 SEEDING, DOMINION EXPERIMENTAL STATION, SWIFT CURRENT, SASK.

Year of charting	1946	1947	1948	
Average number of plants of crested wheatgrass per m²	20.3	17.7	24.4	Ungrazed
Total basal area of crested wheatgrass plants per m²	167.0	227.1	256.5	Ungrazed
Crested wheatgrass cover as a percentage of ground area	1.67	2.27	2.565	Ungrazed
Average number of plants of crested wheatgrass per m²	1.1	2.3	4.0	Grazed
Total basal area of crested wheatgrass plants per m²	1.9	5.8	8.0	Grazed
Crested wheatgrass cover as a percentage of ground area	0.019	0.058	0.08	Grazed

Previous to 1938, there were no plants of crested wheatgrass on the native sod. The results presented in Table 8 show that crested wheatgrass had developed a two and one-half per cent cover during a period of 10 years under complete protection. When grazed, the cover of crested wheatgrass is increasing, but much more slowly.

SUMMARY AND CONCLUSIONS

1. Seed bed, stubble or annual weeds. Native sod not suitable unless the cover is depleted by drought or cultivation.

2. Heavy spring grazing on old stands of crested wheatgrass has resulted in an invasion of other grasses when a source of seed was readily available. The invasion did not occur to the same extent if the crested wheatgrass was protected. There was no invasion of the crested wheatgrass into adjacent native sod.

3. If the seed-bed is suitable, there will be no significant difference after a 10-year period in density of stand or yields when seedings are either broadcast or seeded, and when seeded at rates of 1 to 12 pounds per acre.

4. Spring flooding does not greatly increase the ground cover over that on dryland, but increases the yield by three to four times.

5. Reseedings on native sod will not be successful unless the native cover is destroyed by either drought or cultivation. Protection increases the rate of advance of crested wheatgrass into native sod.

Crested wheatgrass is a hardy perennial grass, well suited to the climatic conditions of Southern Alberta and Saskatchewan, as shown by the experiments conducted by the Dominion Range Experiment Station, Manyberries, Alberta. Heavy grazing is detrimental to stands of crested wheatgrass the first year after seeding before the plants are able to establish themselves. During this period, overgrazing weakens the crested wheatgrass plants to the extent that natural succession takes place more rapidly than in exclosures. When crested wheatgrass has been seeded on overgrazed native prairie, the per cent density of stand appears to be controlled by the condition and vigour of the native vegetation. However, in no case does the stand of crested wheatgrass seem to be decreasing, and in most cases it is increasing, even though very slowly, especially where grazing is practised.

The information indicates that over a period of ten years either the rate of seeding or the cultural method used will have little or no effect on either the density or yield of a stand. In a wet year, the density of the stand will not change to any extent, but the yield may increase considerably. This applies to spring flooded areas where the density of the grass is only increased by 39 per cent, while the yield is increased 370 per cent over crested wheatgrass grown on dryland.

Yields of crested wheatgrass do not appear to follow any definite curve from year to year. Yield seems to depend on available moisture which (1) may triple the amount of hay, or (2) under dry conditions tends to kill out the weaker plants.

ACKNOWLEDGMENTS

Grateful thanks are extended to J. B. Campbell, Officer-in-Charge of Forage Crops, Dominion Experimental Station, Swift Current, Saskatchewan, for his constructive criticism of the manuscript and his invaluable help in preparing the final draft.

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THE SURVIVAL OF GRASSHOPPER NYMPHS ON VEGETATION TREATED WITH 2,4-D[1]

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Fox (1) has drawn attention to a relationship between the use of the selective herbicide 2,4-D and damage to wheat caused by the wireworm *Ctenicera aeripennis destructor* Brown. Where 2,4-D was applied for weed control just prior to the seeding of wheat, the amount of damage the wireworms inflicted on the crop was increased. As the use of 2,4-D for weed control may affect other insects, it seems desirable to record some observations on the effect of this chemical on the survival of grasshoppers, mostly nymphal *Melanoplus m. mexicanus* Sauss. Any environmental factor that alters the percentage survival of this species is of great importance, since the mortality in the early stages is normally high. For example, a small percentage increase or decrease might, on the one hand, double the numbers reaching maturity, or, on the other hand, reduce them to one-half.

The observations were made in 1947 on a field experiment of which the 2,4-D treated plots formed one part. The experiment was laid out on 4 strips of wheat stubble, each one mile long, and all situated on one farm near Milo, Alberta. There were 16 four-acre plots, of which 8 were treated with 2,4-D, and 8 were untreated checks. These were distributed over the experimental area at random, but with local control so that 2 treated and 2 untreated plots were placed on each strip. The experimental area was also divided transversely into two equal blocks, and the distribution of the plots was so controlled that half the replicates were in each block.

The herbicide used was an emulsion concentrate of the butyl ester of 2,4-D, said to contain 32 per cent of the acid equivalent. It was applied with a turbine sprayer at the rate of 16 fluid ounces per acre in about 4 gallons of water. Treatment was carried out on June 16, 1947.

At the time of treatment, the main green vegetation on the plots consisted of stinkweed (*Thlaspi arvense* L.) in flowering and early fruiting stage, Russian thistle (*Salsola pestifer* (A. Nels.) in the succulent foliaceous stage, lambs' quarters (*Chenopodium album* L.) in vegetative to early blooming stage, and tumbling mustard (*Sisymbrium altissimum* L.) in rosette stage. There was little volunteer wheat or other graminaceous species present, which are superficially unaffected by dosages of 2,4-D sufficient for killing the species of weeds listed. Therefore, any grasshoppers present had to feed on weeds, which soon showed the characteristic symptoms following treatment. With the exception of a few tumbling mustard rosettes, the affected plants remained green for the duration of the experiment, up to July 2.

The evaluation of the grasshopper populations was made by 16 separate visual estimates of numbers per square yard on each plot. The sampling procedure was designed to ensure a population estimate reasonably repre-

[1] Contribution No. 2606 from the Division of Entomology, Science Service, Department of Agriculture. This experiment was part of the Prairie Regional Grasshopper Project, under the leadership of R. H. Handford.

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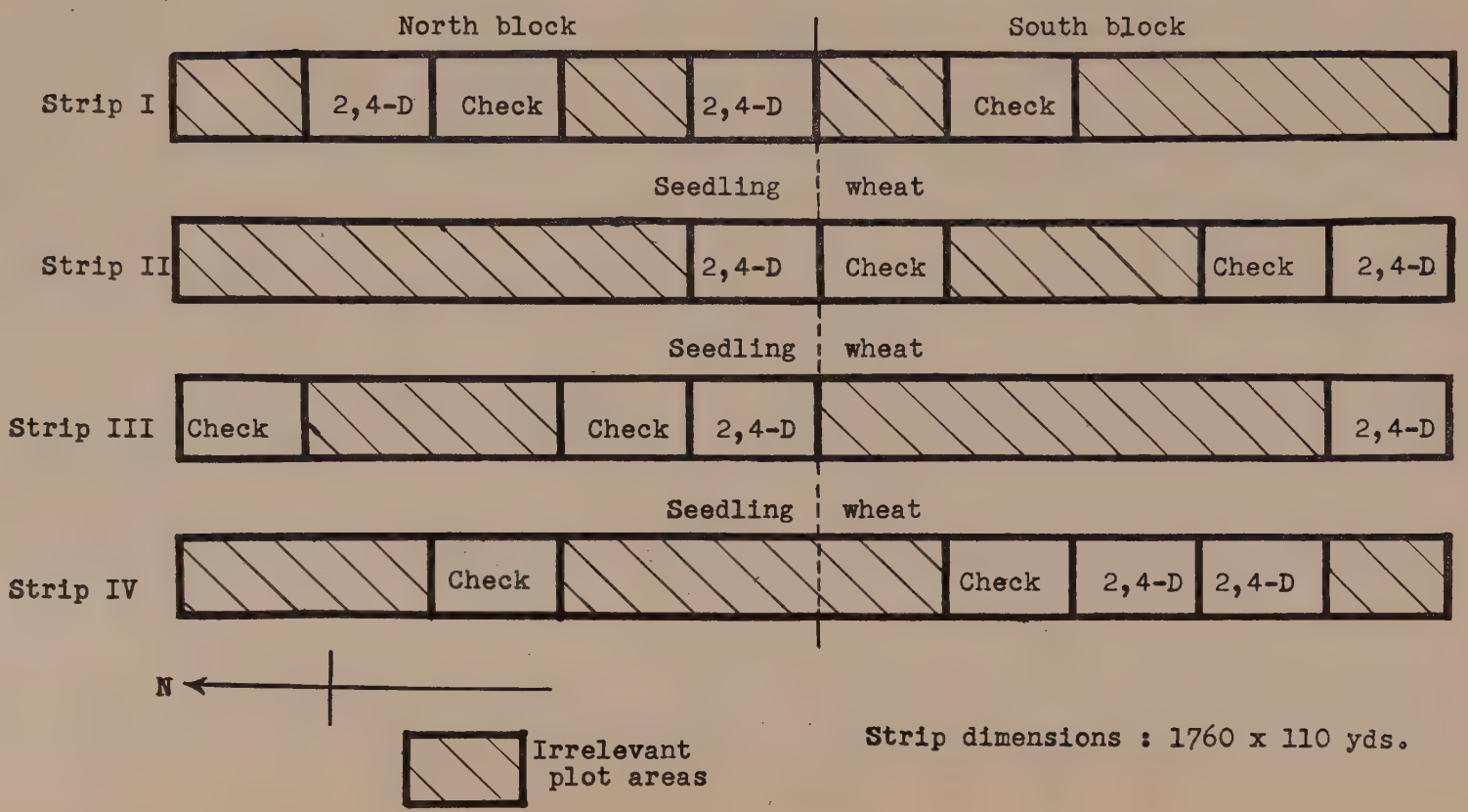
PLAN OF EXPERIMENTAL PLOTS : SURVIVAL OF GRASSHOPPER NYMPHS ON VEGETATION TREATED WITH 2,4-D



Strip dimensions : 1760 x 110 yds.

sentative of the whole plot. Only one complete appraisal of the whole experiment was made, on June 24. Part of the experiment was available for a second appraisal on July 2.

Hatching of *M. mexicanus* eggs occurred later than usual in 1947. At the time the treated plots were sprayed, grasshopper nymphs were very scarce, and when the experiment had to be abandoned on July 2, nymphal development and egg data suggested that hatching was still incomplete. Observations had to be carried out on a basis of very small numbers so that the proportional variability in results was very high.

On June 24, when the first estimates of abundance were made, the average population on the treated plots was estimated at 0.46 per sq. yd., while that on the untreated plots was only 0.23 per sq. yd. When the final observation was made on July 2 on the one remaining strip of the experimental area, the treated plots averaged 4.2, and the untreated plots 2.3 nymphs per sq. yd. The size of the differences, and the degree to which they were consistently observed, would suggest significance, but it was not possible to show this in a formal variance analysis, because the variability from plot to plot was too great.

Tables 1 and 2 are presented in order to indicate the degree to which the ratio between populations on treated and untreated areas varied or was consistent. Table 1 shows how the ratio varied from strip to strip, and that, although there was wide variation, the average population on the treated portions always exceeded that on untreated portions of any given strip. Table 2 shows that when the relative populations on the two *blocks* were considered, they were almost identical both in proportion and in absolute numbers.

TABLE 1.—ESTIMATED GRASSHOPPER POPULATIONS ON 2,4-D TREATED AND UNTREATED VEGETATION WITH REFERENCE TO STRIPS

(Populations per sq. yd. × 32)

Strip	I		II	III	IV	Total
Date	June 24	July 2	June 24	June 24	June 24	June 24
Treated, 2-4-D	23	134	10	15	11	59
Check	13	73	5	2	10	30

TABLE 2.—ESTIMATED GRASSHOPPER POPULATIONS ON 2,4-D TREATED AND UNTREATED VEGETATION, WITH REFERENCE TO BLOCKS

(Population per sq. yd. × 64, as of June 24)

	North block	South block	Total
Treated, 2,4-D	30	29	59
Check	15	15	30

While no formal claims can be made at this time regarding the apparent observation that treatment of weeds with 2,4-D hastens the development or increases the percentage survival of *M. mexicanus*, the evidence seems sufficient to show that such treatment does not depress survival. In fact, it was observed that the most densely populated area in the whole experiment was a patch of lambs' quarters showing typical symptoms of the action of 2,4-D. Therefore, from the point of view of grasshopper control, the use of 2,4-D alone to control weeds, just prior to or during grasshopper hatching, could be a dangerous procedure as compared with some recommended tillage operations carried out in the fall or early spring. This would apply whether 2,4-D treatment is advantageous to grasshoppers or whether it merely does not interfere with them as long as the affected plants remain succulent. It is therefore suggested at this time that where "chemical summer-fallowing" is deemed necessary in the control of soil erosion, and where at the same time grasshoppers are a threat, persons who intend to try chemical summer-fallowing should be prepared to control grasshoppers by means of insecticides.

This work does not establish whether or not any increase in numbers of grasshoppers found in treated vegetation could be a nutritional effect, resulting from changes in the physiology of the food plants. An alternative possibility has been considered—that the distorted plants fail to shade the ground as fully as normal plants. This could result in a higher soil temperature and an accelerated rate of hatching.

Green weeds are probably important to ovipositing *M. mexicanus* in stubble fields. If the general use of herbicides were to result ultimately in the nearly complete removal of susceptible weeds from cereal crop ecology, the long-term effects on grasshoppers might differ from the immediate ones forecast here.

ACKNOWLEDGMENTS

A. H. Carter, of "Green Cross" Insecticides Division, The Sherwin Williams Co., kindly made sufficient 2,4-D available for the experiment. Roy O'Leary, of Queenstown, Alberta, co-operated in an essential way by providing the land necessary for the experimental lay-out.

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DIGESTIBILITY STUDIES WITH RUMINANTS

XIV. THE EFFECT OF THE PLANE OF NUTRITION ON THE DIGESTIBILITY OF BARLEY[1]

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In a previous publication (4) the effect of the level of feeding on the digestibility of rations of equal parts of hay and barley was determined. Using grade Shorthorn steers the total ration was fed at levels of 2, 4, 6.5, 9 and 10 kg. per animal per day. It was found that the digestibility of nitrogen decreased as the plane of nutrition was increased. The total decrease amounted to about 6 absolute per cent and the difference was statistically significant. The digestibility of the nitrogen free extract showed a small decrease of 1.5 absolute per cent which was statistically significant. The digestibilities of the other nutrients did not show much change with the increase in plane of nutrition.

When the coefficients of the barley were calculated from the mixed rations with hay the decreases were intensified. For instance, in the case of the total digestible nutrients the respective values for the 5 increasing levels were 83.6, 84.0, 84.5, 81.9 and 80.4 per cent of the dry matter. This decrease was statistically significant. Any effect of the plane of nutrition on the digestibility of the mixed rations due to the presence of barley would be masked to a certain extent by the presence of an equal amount of hay. It was shown in a previous publication (3) that the plane of nutrition has no effect on the digestibility of hay. To determine the effect on the digestibility of barley the present experiment was carried out. Hay was fed at a constant level and barley at increasing levels. At the same time the coefficients of digestibility of the hay alone were determined.

EXPERIMENTAL

Digestion trials were carried out with six grade Shorthorn steers. They were $1\frac{1}{2}$-2 years old and weighed on an average, throughout the experiment, 430 kilograms. They were numbered 1-6, respectively. Six rations were used. Hay was fed alone at approximately 7 kg. (the average of all six animals was 6.8 kg.). In the mixed rations hay was fed at a level of 3 kg. Various rations were made up by feeding barley at 1, 2, 3, 4 and approximately 5 kg. per day. The quantity of barley given at the highest level of feeding for each animal was based on the maximum amount which that animal could consume. The average of the six trials at the maximum level was 4.73 kg. per animal per day.

The barley was Western Canada Feed No. 1. The hay was largely timothy. The botanical composition is shown in Table 1. The chemical composition of the feeds is given in Table 2.

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[1] Contribution No. 162 from the Division of Chemistry, Science Service, Department of Agriculture in co-operation with the Division of Animal Husbandry, Experimental Farms Service.

[2] Chemist, Division of Chemistry, Science Service.

[3] Technicians Gr. 3.

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TABLE 1.—BOTANICAL ANALYSIS OF MIXED HAY

Type of herbage	Per cent
Timothy	65.7
Legumes (red and alsike clover, alfalfa)	33.4
Couch grass	0.7
Miscellaneous	Trace

TABLE 2.—CHEMICAL COMPOSITION OF FEEDS (MEANS OF 6 VALUES)

Feed	Original dry matter %	Composition of dry matter				
		Ash %	Protein* %	Ether extract %	Crude fibre %	N-free extract %
Hay	87.14	5.49	9.85	1.00	38.04	45.62
Barley	86.01	2.92	12.80	1.87	6.62	75.78

* Protein factors (Jones (2))
Hay – N × 6.25
Barley – N × 5.83.

The experiment was set up in the form of a 6 × 6 randomized Latin square, a different ration being fed to each animal in each of six periods. The collection period was 12 days in length preceded by a preliminary period of 16 days.

Progress of Experiment

There were some feed refusals. In period 2, animal 4 receiving 4 kg. of barley refused some feed and a total of two rations was removed during the first 8 days of the collection period. The results for this animal were calculated on the basis of a 10-day collection period. In the same period animal 6 receiving the maximum quantity of barley refused some feed at the beginning of the preliminary period. It was necessary to adjust the ration for this animal, lengthen the preliminary period and reduce the collection period to 10 days. In period 4, animal 1 receiving the maximum quantity of barley refused its ration on the fourth day of the collection period. Otherwise the ration was consumed satisfactorily. The results in this case were calculated on the basis of an 11-day collection period. Apart from these instances the experiment proceeded satisfactorily. The rations were consumed regularly and all the animals maintained good health.

RESULTS

In Appendix Table 6 the coefficients of digestibility of the total rations for dry matter and nitrogen have been arranged in a Latin square according to ration, period and animal. An analysis of variance is given in Table 7. The data are summarized in Table 3. This table gives the mean coefficients of digestibility of the dry matter and of the nitrogen for each animal and for each period. The "F" values have been included.

TABLE 3.—MEAN COEFFICIENTS OF DIGESTIBILITY OF THE DRY MATTER AND NITROGEN OF THE TOTAL RATIONS ARRANGED BY PERIODS AND BY ANIMALS (MEANS OF SIX VALUES)

Coefficients of digestibility of dry matter				Coefficients of digestibility of nitrogen			
Arranged by animals		Arranged by periods		Arranged by animals		Arranged by periods	
Animal No.	Coefficient %	Period No.	Coefficient %	Animal No.	Coefficient %	Period No.	Coefficient %
1	65.8	1	66.3	1	64.0	1	65.1
2	64.4	2	65.2	2	60.6	2	65.0
3	64.6	3	63.9	3	63.4	3	62.9
4	65.9	4	64.5	4	64.4	4	61.8
5	63.7	5	65.1	5	62.2	5	64.3
6	65.0	6	64.3	6	64.8	6	60.3
F value*	1.09	F value*	1.15	F value*	2.50	F value*	3.68

* Nec. F calculated when 6 rations, 6 animals and 6 periods are arranged in a Latin square, is 2.71 at P = 0.05 and 4.10 at P = 0.01.

It is apparent that there was no significant difference between the animals in their ability to digest the dry matter and nitrogen. There was no significant difference between the periods for dry matter. There was a significant difference between the periods for nitrogen. Periods 1, 2 and 5 were slightly higher than periods 3, 4 and 6. In each case the three periods were similar. There was no particular trend throughout the course of the experiment.

The coefficients of digestibility of the hay and of the barley calculated from the various hay rations are given in Appendix Table 8, with an analysis of variance in Appendix Table 9. In Appendix Table 10 are given the percentage digestibilities of the gross energy of the hay and of the barley calculated from the rations with hay. The analysis of variance is given in Appendix Table 11. All these results have been summarized in Table 4, which includes the necessary differences for significance.

TABLE 4.—MEAN COEFFICIENTS OF DIGESTIBILITY OF NUTRIENTS OF BARLEY CALCULATED FROM MIXED RATIONS WITH HAY. (MEANS OF SIX VALUES)

Ratios of hay to barley in rations		Mean coefficients of digestibility of following nutrients						T.D.N. in per cent of dry matter
Hay	Barley	Dry matter	Organic matter	Nitrogen	Ether extract	Total carbo-hydrates	Gross energy	
Kg.	Kg.	%	%	%	%	%	%	
3	1	85.0	87.6	73.2	80.0	89.9	85.0	87.5
3	2	81.8	83.7	74.6	84.6	85.2	81.9	84.0
3	3	80.0	80.0	72.8	80.5	83.5	79.4	82.0
3	4	77.0	78.9	70.7	74.2	80.3	76.0	79.0
3	5*	73.3	75.1	66.7	61.1	76.8	72.2	75.0
Nec. diff. at P = 0.05		5.8	5.6	5.9	11.5	5.7	6.0	5.5

* Approximately according to capacity of animals.

It is evident from this table that the digestibility was lowest at the maximum level of feeding. With the exception of nitrogen and ether extract it was highest at the lowest level of feeding. In the case of these two nutrients there was no statistically significant change in the three lower levels. Then the digestibility decreased. These results confirm the findings of the previous paper (4). The differences are of a larger magnitude in view of the fact that barley alone was increased.

The levels of feeding were translated into terms of planes of nutrition by using Brody's tables of maintenance requirements (1). For each ration the weights of the six animals were averaged and their requirements in total digestible nutrients and digestible protein estimated according to Brody's formulae. The daily consumption for each ration was averaged for the six animals and the content in T.D.N. and digestible protein determined. These values have been expressed in Table 5.

TABLE 5.—PLANE OF NUTRITION EXPRESSED IN TERMS OF MAINTENANCE REQUIREMENTS USING BRODY'S FORMULAE (1). (MEANS FOR SIX ANIMALS ON EACH RATION)

Ration		Daily nutrients required and consumed					
		T.D.N.			Digestible protein		
Hay	Barley	Consumed daily	Required	Per cent consumed of requirements	Consumed daily	Required	Per cent consumed of requirements
Kg.	Kg.	Kg.	Kg.		Gm.	Gm.	
6.5	0	3.20	3.04	105	318	316	101
3	1	2.17	2.88	75	226	299	76
3	2	2.86	2.91	98	317	302	105
3	3	3.54	2.94	120	398	305	130
3	4	4.13	2.98	139	474	309	153
3	5*	4.46	3.01	148	512	312	164

* Approximately, according to capacity of animals.

It will be observed that for the T.D.N., the hay ration was fed at approximately the maintenance level and the barley-hay rations at from 0.75 to approximately 1.5 maintenance. As far as digestible protein was concerned the hay ration was fed at approximately the maintenance level and the barley-hay rations at levels of from approximately 0.75 to 1.6 maintenance.

SUMMARY AND CONCLUSIONS

1. Six grade Shorthorn steers were fed rations of hay alone and of hay with increasing quantities of barley.

2. The hay was fed at approximately maintenance level and the mixed rations were fed at levels of approximately 0.75 to 1.5 maintenance.

3. The coefficients of digestibility of barley were calculated from the mixed rations with hay.

4. It was found that as the plane of nutrition increased the digestibility of the barley decreased.

ACKNOWLEDGMENTS

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APPENDIX

TABLE 6.—COEFFICIENTS OF DIGESTIBILITY OF DRY MATTER AND NITROGEN OF TOTAL RATIONS ARRANGED BY RATIONS, PERIODS AND ANIMALS (ANIMAL NUMBERS SHOWN IN BRACKETS, COEFFICIENTS IN PER CENT)

Nutrient	Period No.	Coefficients of following rations					
		Hay	Mixtures of hay : barley				
			3 : 1	3 : 2	3 : 3	3 : 4	3 : max.
Dry matter	1	57.0 (2)	64.5 (1)	67.4 (3)	67.5 (5)	68.7 (4)	72.8 (6)
	2	56.6 (3)	67.0 (4)	65.6 (5)	70.0 (1)	69.4 (6)	62.7 (2)
	3	55.6 (6)	62.1 (3)	67.5 (1)	67.7 (2)	63.9 (5)	66.5 (4)
	4	55.9 (5)	61.1 (6)	66.9 (2)	68.1 (4)	67.9 (3)	67.1 (1)
	5	56.6 (1)	63.7 (5)	67.9 (4)	67.5 (6)	69.6 (2)	65.1 (3)
	6	57.0 (4)	62.5 (2)	63.7 (6)	68.2 (3)	68.8 (1)	65.5 (5)
Nitrogen	1	56.9 (2)	61.1 (1)	66.5 (3)	67.8 (5)	66.7 (4)	71.4 (6)
	2	62.2 (3)	67.4 (4)	64.7 (5)	69.3 (1)	67.5 (6)	59.1 (2)
	3	55.8 (6)	61.1 (3)	67.6 (1)	64.0 (2)	63.6 (5)	65.1 (4)
	4	53.2 (5)	63.2 (6)	61.0 (2)	65.1 (4)	66.2 (3)	61.9 (1)
	5	58.8 (1)	61.7 (5)	69.6 (4)	68.0 (6)	65.7 (2)	62.0 (3)
	6	52.7 (4)	56.6 (2)	62.9 (6)	62.2 (3)	65.2 (1)	62.0 (5)

TABLE 7.—ANALYSIS OF VARIANCE OF DATA IN TABLE 6‡

Nutrient	Variance due to	D/F	Sums of squares†	Variance†	F
Dry matter	Ration	5	597.04	119.408	*
	Period	5	22.24	4.45	1.15
	Animal	5	21.12	4.22	1.09
	Error	20	77.20	3.86	—
Nitrogen	Ration	5	392.16	78.43	12.78
	Period	5	112.94	22.59	3.68
	Animal	5	76.87	15.37	2.50
	Error	20	122.78	6.14	—

‡ Nec. F. for $N_1 = 5$, $N_2 = 20$ at P of 0.05 = 2.71.
Nec. F. for $N_1 = 5$, $N_2 = 20$ at P of 0.01 = 4.10.
* Obviously significant.
† Calculated to four decimal places, reported to two.

TABLE 8.—COEFFICIENTS OF DIGESTIBILITY OF NUTRIENTS IN HAY AND OF NUTRIENTS IN BARLEY CALCULATED FROM MIXED RATIONS WITH HAY, ARRANGED BY RATIONS, PERIODS AND ANIMALS. (ANIMAL NUMBERS IN BRACKETS, COEFFICIENTS IN PER CENT)

Nutrient	Period No.	Coefficients of digestibility					
		Hay	Barley calculated from the following ration with hay				
			H–3 B–1	H–3 B–2	H–3 B–3	H–3 B–4	H–3 B-Max.
Dry matter	1	57.0 (2)	89.4 (1)	84.4 (3)	78.9 (5)	78.2 (4)	84.8 (6)
	2	56.6 (3)	99.1 (4)	79.6 (5)	83.7 (1)	79.2 (6)	66.6 (2)
	3	55.6 (6)	79.3 (3)	84.3 (1)	79.2 (2)	69.7 (5)	72.9 (4)
	4	55.9 (5)	75.3 (6)	82.9 (2)	79.8 (4)	76.7 (3)	73.6 (1)
	5	56.6 (1)	85.8 (5)	85.3 (4)	78.6 (6)	79.7 (2)	70.6 (3)
	6	57.0 (4)	80.8 (2)	74.6 (6)	80.0 (3)	78.2 (1)	71.2 (5)
Organic matter	1	58.4 (2)	93.4 (1)	86.3 (3)	80.2 (5)	80.9 (4)	85.9 (6)
	2	57.5 (3)	102.2 (4)	81.5 (5)	86.0 (1)	81.0 (6)	69.4 (2)
	3	56.5 (6)	82.3 (3)	86.2 (1)	81.3 (2)	71.2 (5)	74.8 (4)
	4	57.0 (5)	77.4 (6)	84.8 (2)	82.0 (4)	78.9 (3)	75.5 (1)
	5	57.6 (1)	86.7 (5)	87.1 (4)	80.6 (6)	81.6 (2)	72.3 (3)
	6	58.3 (4)	83.3 (2)	76.3 (6)	82.0 (3)	79.9 (1)	72.9 (5)
Nitrogen	1	56.9 (2)	71.0 (1)	77.2 (3)	76.0 (5)	72.1 (4)	79.1 (6)
	2	62.2 (3)	92.4 (4)	74.0 (5)	79.1 (1)	73.8 (6)	60.3 (2)
	3	55.8 (6)	69.5 (3)	77.8 (1)	68.6 (2)	66.9 (5)	68.4 (4)
	4	53.2 (5)	76.5 (6)	65.4 (2)	70.9 (4)	71.1 (3)	64.0 (1)
	5	58.8 (1)	73.5 (5)	84.5 (4)	76.7 (6)	70.9 (2)	64.5 (3)
	6	52.7 (4)	56.3 (2)	69.0 (6)	65.8 (3)	69.4 (1)	64.1 (5)
Ether extract	1	35.2 (2)	55.8 (1)	88.1 (3)	82.0 (5)	58.7 (4)	70.3 (6)
	2	30.3 (3)	94.1 (4)	84.4 (5)	79.2 (1)	80.9 (6)	40.8 (2)
	3	34.1 (6)	97.5 (3)	90.6 (1)	86.8 (2)	81.2 (5)	71.8 (4)
	4	25.0 (5)	82.0 (6)	86.6 (2)	83.1 (4)	77.4 (3)	81.7 (1)
	5	17.2 (1)	83.0 (5)	86.3 (4)	70.3 (6)	77.6 (2)	61.6 (3)
	6	9.6 (4)	67.6 (2)	71.3 (6)	81.7 (3)	69.3 (1)	60.2 (5)
Crude fibre	1	55.9 (2)	129.2 (1)	46.2 (3)	−8.5 (5)	21.2 (4)	29.7 (6)
	2	50.3 (3)	136.0 (4)	−8.7 (5)	36.0 (1)	−11.7 (6)	−43.8 (2)
	3	53.1 (6)	50.7 (3)	50.7 (1)	20.5 (2)	−47.5 (5)	− 7.8 (4)
	4	51.0 (5)	−95.2 (5)	55.3 (2)	5.2 (4)	− 8.4 (3)	− 6.2 (1)
	5	52.1 (1)	3.4 (5)	5.4 (4)	3.3 (6)	24.1 (2)	−50.5 (3)
	6	58.1 (4)	99.3 (2)	−16.0 (6)	31.9 (3)	39.7 (1)	− 8.5 (5)
Nitrogen free extract	1	61.0 (2)	94.3 (1)	91.0 (3)	87.7 (5)	87.3 (4)	91.6 (6)
	2	62.2 (3)	101.1 (4)	90.3 (5)	91.3 (1)	90.1 (6)	81.3 (2)
	3	59.6 (6)	88.7 (3)	91.2 (1)	88.8 (2)	82.3 (5)	83.5 (4)
	4	62.1 (5)	91.8 (6)	90.2 (2)	90.6 (4)	87.4 (3)	84.7 (1)
	5	62.4 (1)	96.7 (5)	95.3 (4)	88.9 (6)	88.8 (2)	85.2 (3)
	6	59.6 (4)	85.7 (2)	86.5 (6)	89.3 (3)	85.8 (1)	82.5 (5)
T.D.N.	1	55.6 (2)	92.0 (1)	86.4 (3)	80.1 (5)	80.2 (4)	85.4 (6)
	2	54.6 (3)	102.3 (4)	82.1 (5)	86.1 (1)	81.6 (6)	69.2 (2)
	3	54.0 (6)	84.3 (3)	87.0 (1)	81.7 (2)	71.8 (5)	75.1 (4)
	4	53.1 (5)	77.7 (6)	84.9 (2)	81.8 (4)	79.0 (3)	75.4 (1)
	5	54.0 (1)	86.6 (5)	87.4 (4)	80.7 (6)	81.5 (2)	72.2 (3)
	6	54.2 (4)	82.1 (2)	76.3 (6)	81.8 (3)	79.7 (1)	72.7 (5)

TABLE 9.—ANALYSIS OF VARIANCE OF DATA IN TABLE 8‡

Nutrient	Variance due to	D/F	Sums of squares§	Variance§	F
Dry matter	Ration	5	3,120.30	*	—
	Period	5	147.59	29.52	1.29
	Animal	5	129.29	25.86	1.13
	Error	20	445.96	22.97	—
Organic matter	Ration	5	3,392.70	*	—
	Period	5	160.74	32.15	1.51
	Animal	5	160.24	32.05	1.51
	Error	20	425.05	21.25	—
Nitrogen	Ration	5	1,356.29	*	—
	Period	5	481.49	96.29	3.99
	Animal	5	394.89	78.98	3.27
	Error	20	482.44	24.12	—
Ether extract extract	Ration	5	14,933.17	2,986.63	32.73
	Period	5	956.84	191.37	2.10
	Animal	5	368.69	73.74	†
	Error	20	1,825.05	91.25	—
Crude fibre	Ration	5	22,533.98	4,506.80	2.91
	Period	5	8,669.55	1,733.91	1.12
	Animal	5	15,633.87	3,126.77	2.02
	Error	20	31,004.26	1,550.21	—
N.F.E.	Ration	5	4,126.16	*	—
	Period	5	116.52	23.30	3.10
	Animal	5	46.34	9.27	1.24
	Error	20	150.08	7.50	—
T.D.N.	Ration	5	4,261.44	852.29	—
	Period	5	150.33	30.17	1.44
	Animal	5	142.54	28.51	1.36
	Error	20	419.74	20.99	—

‡ Nec. F for $N_1 = 5$, $N_2 = 20$ at P of 0.05 is 2.71 at P of 0.01 is 4.10.
* Obviously significant
† Variance for animal less than variance for error
§ Calculated to four decimal places, reported to two.

TABLE 10.—PER CENT DIGESTIBILITY OF GROSS ENERGY OF HAY AND OF BARLEY CALCULATED FROM RATIONS WITH HAY ARRANGED BY RATIONS, PERIODS AND ANIMALS. (ANIMAL NUMBERS IN BRACKETS, COEFFICIENTS IN PER CENT)

Period	Digestibility of energy					
	Hay	Barley calculated from following rations with hay				
		H–3 B–1	H–3 B–2	H–3 B–3	H–3 B–4	H–3 B–4.7*
1	53.2 (2)	87.7 (1)	84.4 (3)	78.0 (5)	76.8 (4)	84.4 (6)
2	51.7 (3)	97.8 (4)	76.4 (5)	82.6 (1)	76.4 (6)	65.4 (2)
3	50.5 (6)	75.9 (3)	83.9 (1)	77.2 (2)	67.5 (5)	70.5 (4)
4	53.2 (5)	77.9 (6)	85.9 (2)	79.0 (4)	77.3 (3)	72.0 (1)
5	54.9 (1)	88.8 (5)	86.4 (4)	79.1 (6)	80.0 (2)	70.1 (3)
6	52.9 (4)	81.7 (2)	74.2 (6)	80.5 (3)	78.1 (1)	70.9 (5)

TABLE 11.—ANALYSIS OF VARIANCE OF DATA IN TABLE 10

Variance due to	D/F	Sums of squares†	Variance†	F	Nec. "F" at P = 0.05
Ration	5	4,014.74	*	*	2.60
Period	5	168.17	33.63	1.30	—
Animal	5	108.34	21.67	§	—
Error	20	518.17	25.91	—	—
Total	35	—	—	—	—

* Obviously significant.
§ Variance less than error variance.
† Calculated to four decimal places, reported to two.

BOOK REVIEW

THE JOURNAL OF SOIL SCIENCE, Volume 1, Number 1, March, 1949. Oxford University Press, Amen House, London, E.C. 4; Canadian Branch, University Ave., Toronto 2, Ont. $4.25.

The British Society of Soil Science has issued the first number of a new Journal, devoted to all aspects of the science of the soil. The journal is sent free of charge to members of the Society. Two numbers will constitute an annual volume.

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